celeration; most buildings fall in this category. The flexible structures have larger natural period (towards the right of the velocity-sensitive region), and their response is governed by the ground displacement, for example, large span bridges.

The codes of Columbia and the Philippines do not allow ESMA for buildings on deep, soft clayey soils, which are likely to amplify the ground motion and cause buildings to experience larger-than-expected seismic forces. All the conditions specified in Table 1 for a particular code must be satisfied for the use of ESMA.

India lies in one of the most seismically active regions of the world. However, the provisions[4] in IS:1893-2002 governing the method of analysis to be used for seismic design of buildings are the most liberal. Use of ESMA could have been justified when computers were not available easily. Now, with high-speed digital computers available easily, several specialized software are available at an affordable price, which can be used for static and dynamic analysis considering linear and nonlinear behaviour.

The primary motive of this correspondence is to alert the readers that time has come to switch over to linear/nonlinear dynamic and pushover analysis methods, which not only provide better understanding of structural behaviour but also improved estimates of member design forces. The restrictions[4] in IS:1893-2002 governing the choice of methods of analysis need serious reviews and revision.

1. Housner, G. W., Proceedings of the Eighth World Conference on Earthquake Engineering, San Francisco, California, Prentice-Hall, NJ, 20–28 July 1984, pp. 25–39.
2. World List, International Association for Earthquake Engineering, Tokyo, Japan, 2004.
3. Rai, D. C., *Curr. Sci.*, 2000, **79**, 1291–1300.
4. IS: 1893–2002, Bureau of Indian Standards, New Delhi, 2002.
5. IBC: 2003, International Building Code, International Code Council, Inc., Viginia, USA, 2003.

ACKNOWLEDGEMENTS. We acknowledge financial assistance provided by the Ministry of Human Resource Development, Government of India.

Received 5 August 2005; revised accepted 22 June 2006

HEMANT B. KAUSHIK
DURGESH C. RAI*
SUDHIR K. JAIN

Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur 208 016, India
**For correspondence.*
e-mail: dcrai@iitk.ac.in

A preliminary report on the possible impact crater of Kachchh

Only a few craters formed due to the impact of extraterrestrial objects are known in India, e.g. Lonar crater of Maharashtra[1,2], Ramgarh[3] and Dhala[4]. This is a preliminary report of yet another possible impact crater in Kachchh district of western India. While most other recognized craters are located within hard rocks, this possible impact crater has a special significance as it is located within an extremely low-lying, flat terrain comprising unconsolidated soft sediments, and its appearance is unconventional and deceptive. Its importance is further augmented as an ancient human settlement belonging to the Harappan period[5] is located about a kilometre southwest of the crater and the ancient Sanskrit texts refer to the impact of a burning extraterrestrial object in the western part of India some 4000–5000 years ago and the suspected area of impact happens to be the Great Rann in the district of Kachchh[6].

The suspected impact crater is seen as a circular feature near the village Luna, located in the northwestern part of Banni Plains (Figure 1) at lat. 23°42′17″N long. 69°15′37″E. The site lies within extensively laid unconsolidated sediments, and the altitude of the region is scarcely around 3–5 m from the sea level. The inner part of the rim–crater junction is better defined than the outer rim due to vegetation. It measures 1.2 km E–W (~ 2.11 outer rim), 1.2 km N–S (~2.15 outer rim). The circular crater forms a shallow depression filled with sediments and the lowest point of the depression is hardly 2 m above the mean sea level. The rim of the crater rises about 2 m from the surroundings, which in turn averages to around 3.5 m. There is a dense growth of variety of *Acacia* species, *Acacia nilotica* (locally known as 'desi baval') at the inner part of the rim and surrounding it is the wild variety of the same, *Prosopsis julifora* (locally known as 'gando baval'). The villagers claim that the growth of the wild thorny plants is only a recent phenomenon, about 3–4 decades; in fact growth of 'gando baval' (meaning '*crazy plant*' in Gujarati) has become a menace all over Kachchh district in recent times. The circular depression is filled with potable water during the rainy season that eventually dries up during summer. It retains water till November–December, making it to appear like a flourishing lake (Figure 2 *a*). Over a length of period several wells are dug in the region of the rim. Till the middle of the twentieth century, the depression is said to have had sufficient water during summer as well. As interpreted by the villagers, due to the construction of several dams along Kachchh Mainland Hill Range, the rivers of the mainland in recent years have stopped disposing rainwater into Banni region, rendering the lake dry during summer. Luna lake is one of the few places where the rare variety of bird, the glassy ibis breeds. According to local villagers, the central part of the depression was dug two and a half decades ago for retaining rainwater during summer, which however, has been silted up in due course. Digging for storing rainwater during summer was also carried at one more place near the ancient human settlement described above. Along with numerous artefacts, several bones were also unearthed, due to which further digging was intervened by the district authorities. Although the present-day rainfall is scanty (average: 322.2 mm/yr – Kachchh Gazetteer), occasional heavy downpour causes complete submergence of the whole surrounding region due to lack of gradient. Water stagnates for considerable time, and the depressions get silted up and the heap of excavated loose earth is levelled up rapidly.

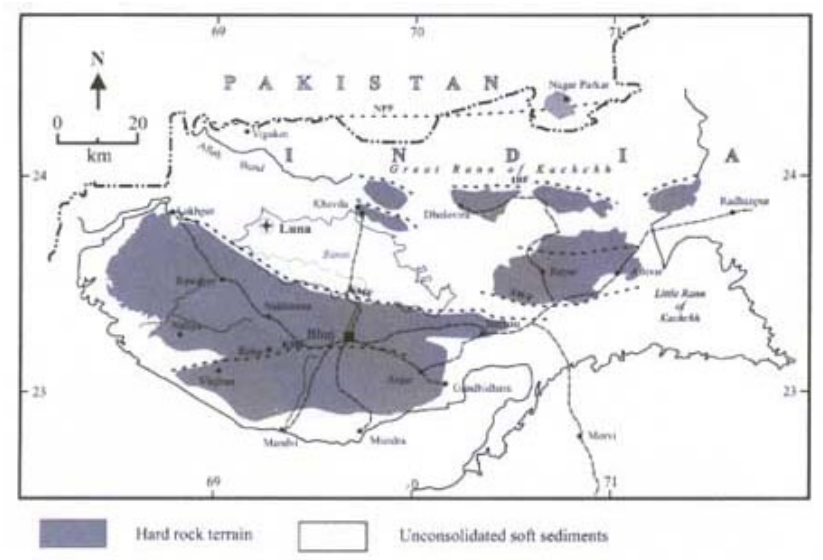

Figure 1. Location map: Kachchh.

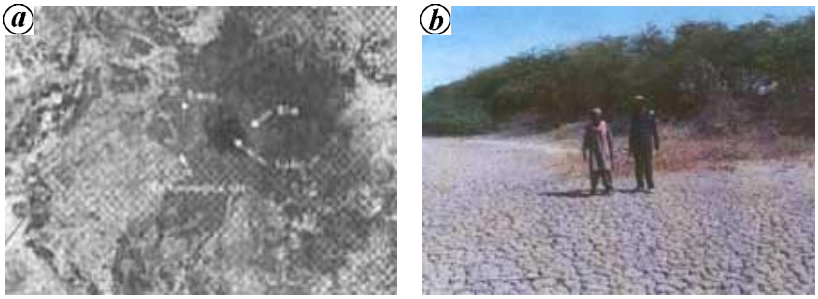

Figure 2. ***a***, Satellite image comprising circular Luna lake. ***b***, Dry bed of Luna lake during summer.

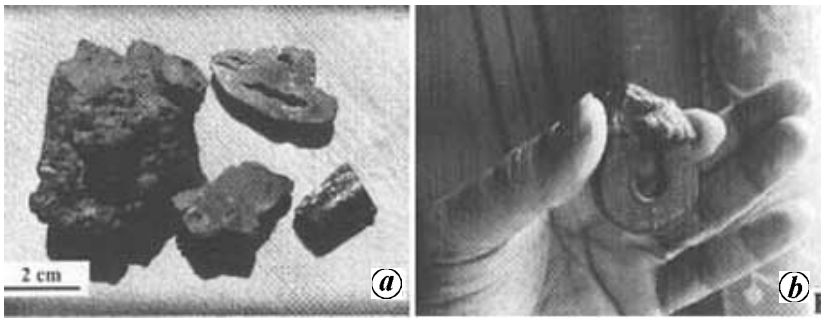

Figure 3. Dark and heavy lumps collected at the rim of Luna lake. ***a***, Largest chunk on the left measures 5 cm across, tubular sample in the lower right is glassy in nature (category-2), and the two samples in the centre are cut and polished for further studies. ***b***, Sample (category-1) strongly attracted to horseshoe-shaped hand magnet.

The effect of rapid siltation of the crater and erosion of the rim is such that conventionally measured depth to diameter ratio is dismally low. Rim and central part of almost 1 km wide depression hardly has 3–4 m of difference (Figure 2 *b*) and from the surrounding plains is also negligible. Banni Plains is an example with its huge extent of around 50 km × 50 km and the highest point above the mean sea level measured merely 9 m and its border with the Great Rann of Kachchh barely 2 m.

Several lumps of dark and heavy objects measuring 2–6 cm were recovered from the rim part of the structure (Figure 3 *a*). Most lumps were of irregular shape consisting of numerous spherical cavities and some were strongly attracted to hand-magnets (Figure 3 *b*). Based on the petrographic study of thin sections cut from the samples collected, they can be classified into three categories: (i) completely dark and opaque, (ii) completely transparent (in thin sections only, in hand specimens more or less opaque) and isotropic (under crossed nicols), and (iii) areas comprising both dark–opaque and transparent–isotropic materials. Those belonging to category-1 are found to be strongly attracted to the hand-magnet and those in category-2 have obsidian-like appearance with vitreous lustre and conchoidal fracture. All the three are blackish and opaque in hand specimens; nonetheless category-2 samples are transparent only along thin edges. Category-1 samples are likely to be metallic meteorite fragments. Under microscope, polished samples belonging to category-1 exhibit thin shimmering lines that apparently resemble 'Neumann lines' (of kamacite) commonly observed in iron–nickel meteorites[7,8]. However, it is proposed to confirm the same by appropriate analysis. Specimens of category-2 can be compared to 'tektites' formed on account of melting of the material of the site of impact and immediate solidification into glass due to enormous heat generated by the impact.

The terrain in which the suspected impact crater is located makes it a unique setting for investigation. Generally craters generated by the impact of an extra-terrestrial object in a hard-rock terrain, as is the case in most impact sites studied, can be recognized by features such as: (i) shattered and up-turned beds, (ii) quaquaversal dips of beds and slump folds, (iii) easily recognizable rim and crater with distinct rim and crater ratio, (iv) fragments of meteorite, (v) occurrence of high pressure minerals, and (vi) occurrence of glassy materials (tektites) formed on account of melting of rocks/minerals at the site of impact. As described earlier, since the impact site comprises loose, unconsolidated sediments and subsequent erosion, the debilitated stature of the rim formed on account of impact and ratio of rim and depression of the crater appears to be quite different from most others studied. Among the various objects/products expected in an impact site, (a) fragments

appearing like metallic meteorites that are dark, heavy and magnetic with spherical cavities are found at the rim of the suspected crater, and (b) glassy objects comparable to tektites have been recovered. Search for high-pressure minerals is planned for the future.

There is further scope for exploring the possibility of correlation of this site with the impact site mentioned in ancient Sanskrit texts. According to Iyengar[6], the Rann of Kachchh was referred to as 'Irina' in the *Rgveda* and a few other Sanskrit texts, where a fireball/meteorite had fallen. Perhaps dating of this event by modern methods could reveal the age of some of the Sanskrit texts that have described the incidence. The archaeological site mentioned above is located about 1 km southwest of the suspected crater. According to Rao, the ruins of the settlement belong to Harappan age (around 4000 years old). As stated earlier, did the heap of bones obtained while digging for storing water in this location two and a half decades ago indicate mass destruction due to the impact or did the Harappans come to live near the lake that filled the impact crater sometime after the event of impact? Only a detailed study can reveal whether the disaster struck when the settlement was flourishing or the Harappans happend to settle there after the creation of the crater, which had capacity to store water.

It is quite appropriate to discuss here the editorial note of Radhakrishna[9], mainly based on Iyengar's paper[6], that the region of Gujarat, Kachchh and parts of Rajasthan are the sites of disaster, of which the extraterrestrial impact could be one. His remarks are noteworthy: '… The course of human history appears to be intercepted by catastrophic events with site of destruction, major cultural discontinuities and migration of people lending support to such an inference. If this is true, impact of meteorites could be the cause for major natural disasters on earth in future as has happened in the past …'[9]. There is a possibility that the meteorite had split into several fragments before falling, with Luna being one of the sites. Thus there could be many more impact sites of this period in and around Kachchh in western India. Was the impact of extraterrestrial objects a cause of the mysterious disappearance of Harappans?

This note is only a preliminary report and further work is in progress. Polished samples of the specimens have been sent for chemical analysis to confirm whether their composition conforms to that of meteorites and the products of impact.

1. Crawford, A. R., *Nature*, 1972, **237**, 96.
2. Fredricksson, K., Dube, A., Milton, J. and Balasundaram, M. S., *Science*, 1973, **180**, 862–864.
3. Dietz, R. S. and McHone, J., *Meteoritics*, **9**, 329–333.
4. Pati, J. R., Abstr. 5092: Annual Meeting of the Meteoritical Society, Gatlinburg, Tennessee, USA, 2005.
5. Joshi, J., Report, Archaeological Survey of India, 1990, p. 435.
6. Iyengar, R. N., *Indian J. Hist. Sci.*, 2004, **39**, 11–49.
7. Buchwald, V., *The Handbook of Iron Meteorites*, University of California Press, 1975.
8. *McGraw-Hill Encyclopaedia of the Geological Sciences* (4th edn), McGraw-Hill, 1977, pp. 471–480.
9. Radhakrishna, B. P., *J. Geol. Soc. India*, 2004, **64**, 127–132.

ACKNOWLEDGEMENT. R.V.K. and M.S.G. thank SAC (ISRO), Ahmedabad for financial assistance through research project no. MWRD: III.1.3.

Received 25 May 2006; revised accepted 6 July 2006

R. V. KARANTH[1,3,*]
P. S. THAKKER[2]
M. S. GADHAVI[1]

[1]*Department of Geology, M.S. University of Baroda, Vadodara 390 002, India*
[2]*Space Applications Centre, Ahmedabad 380 015, India*
[3]*Present address: 104, 'Aarth', 29, Pratapgunj, Vadodara 390 002, India*
**For correspondence.*
e-mail: r_v_karanth@yahoo.co.in