Meteorite Research in India

Introduction:

Meteorites have been aptly described as 'poor man's space probes'. They have stored in them the past history of the solar system in the form of physical, chemical and isotopic changes and it is for us to decipher this information by detailed laboratory investigations. These priceless samples have been recognised as extraterrestrial in 1794 by the French lawyer Ernst Florens Friedrich Chaldni. Meteorites are broken pieces of asteroids, and are delivered to Earth free of cost by nature, as a result of gravitational perturbations in the interplanetary space.

The broad objectives of the meteorite studies are to (i) decipher the chemical and isotopic composition of the 'solar nebula' that evolved to form the solar system objects, (ii) understand how the solar system formed and its connection with stellar environment, (iii) understand the various physico-chemical processes and their time scales that have lead to the present state of the solar system, (iv) understand the evolution of terrestrial planets including Earth and (v) probe the origin and evolution of life.

Figure 1: *A glimpse of some of the important meteorite falls in India*

Meteorite repository and classification:

The meteorite samples are well preserved by professional organisations world over. Every country has its own regulations and legislation that govern the ownership of a meteorite that is either an observed fall (seen at the time of fall and recovered) or a later find (not seen at the time of fall and collected later and confirmed to be a meteorite). In India the Geological Survey of India (GSI) is the custodian of all meteorite falls/finds in the country. Meteorite samples for scientific research can in principle be obtained from the official (e.g. GSI) as well as private custodian (in foreign countries) to carry out scientific studies. During the past 40 years the world's collection of meteorite (falls/finds) has increased from about 2000 to nearly 40000, primarily due to addition of meteorite "finds" through systematic search in cold (Antarctica) and hot desert (in Africa), enriching the types of meteorites (and their parent asteroids, including some that are fragments of the Moon and Mars) at our disposal for detailed laboratory investigation. An immediate objective, when a new meteorite has been identified, is to classify it properly for further detailed studies with deserved attention. The classification of meteorites has evolved over the decades to give us information about their formation environment (nearer or farther from Sun), thermal and aqueous processing and/or melting and chemical differentiation of its parent body (asteroid), based on studies of their chemical, petrological and isotopic systematic. This classification allows us to select the proper meteorite sample that is pertinent to the specific aspect under investigation. Despite this detailed knowledge base, we still keep finding 'first of its kind' meteorites, making each meteorite fall/find a very interesting object for detailed study.

In India, GSI, Kolkata is the repository of all the meteorites that fell in India. We have an impressive collection of about 150 falls/finds that include some very precious meteorites (Tonk, Semarkona, Bishunpur, Chainpur, Shergotty, Piplia Kalan), and well studied and large falls (Dhajala, Sulagiri and 'Katol', the most recent fall of May 22, 2012, near Nagpur).

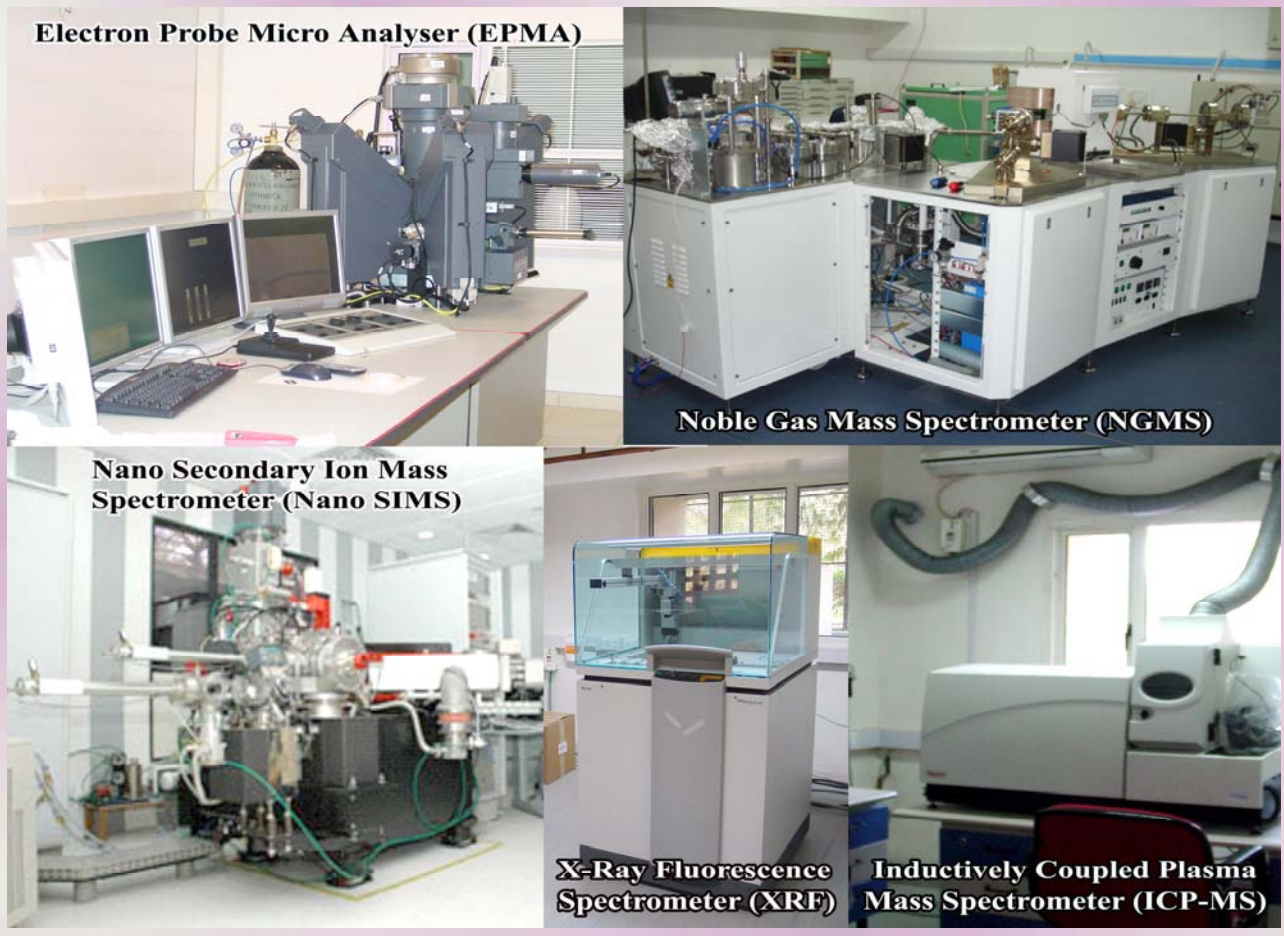

Figure 2: *State-of-the-art instruments at PRL for meteorite analysis*

Global scenario:

Since the recognition by Suess and Urey in the 1950s that meteorites provide the key to infer chemical composition of the Sun, the focus has been on obtaining the elemental and isotopic composition and age of different types of meteorites. The advanced analytical techniques developed to analyse the returned Moon samples have been successfully employed for meteorite studies to lay a sound frame work of their chronology and isotopic systematic, using the now extinct short lived radio nuclides that provided new information on early solar system processes and time scales. The discovery of interstellar grains in meteorites, as a result of painstaking efforts to isolate the carrier phase(s) of anomalous Xenon isotopic abundances by the Chicago group of Ed Anders, in the seventies, has further expanded the scope of meteorite studies to probe stellar nucleosynthesis and solar-stellar connection. Advanced mass spectrometers and sample characterisation tools presently allow a detailed study of mineral, chemical and isotopic composition of micron sized particles of either cometary grains from Stardust mission, IDPs from stratosphere and/or in situ study of micro-phases present in thin/thick sections of meteorites, pushing further the frontiers in meteorite research.

Indian Scenario:

Meteorite studies in India have been initiated at two Institutes (TIFR, Bombay and IIT Kanpur) in late 1960s. The initial focus was to use meteorites as probes to understand Solar and Galactic Cosmic Rays, through studies of records of their interaction preserved in meteorites that were exposed to cosmic rays in interplanetary space for millions of years. These studies led to very significant results that include discovery of ancient solar flare records in meteorites and constancy of solar and galactic cosmic ray fluxes over long (million year) time scales. The areas of interest slowly expanded to chemical and isotopic investigations with the aim of understanding early solar system processes, including solar-stellar connection and the time scales of these processes; evolution of volatiles on terrestrial planets and understanding the dynamical processes involved in the meteorite delivery to Earth. Sophisticated analytical facilities like low background radiation counting

systems, noble gas mass spectrometers, ion and electron micro probes, secondary ion mass spectrometers (and lately Nano SIMS) have been used to characterise phases in sections and subject these for high spatial resolution isotopic analysis. Also, the process of meteorite impact leading to crater formation and consequent effects on the environment and the life therein have been addressed by looking at meteorite specific siderophile elements in impact glasses and geological boundaries. Some major outcome of these studies are: 1) The realization that some primitive meteorites host refractory oxides and silicates that are some of the first solids to form in the solar system, which has opened a new window to study the events and time scales leading to the origin and early evolution of the solar system; 2) Meticulous studies of isotope records in early solar system solids using secondary ion and noble gas mass spectrometry techniques, primarily done at the Physical Research Laboratory, led to the identification of fossil records of short-lived nuclides of stellar origin in early solar system solids; 3) Studies of these records provided a chronological framework for the origin and early evolution of the solar system and led to the identification of the short-lived nuclide 26Al as the heat source for early melting of planetesimals and bolstered the proposal for a supernova triggered origin of our solar system; 4) Identification of records of ancient Martian atmosphere in the meteorite ALH84001 has led to the understanding of the evolution of Mars atmosphere.

Future Perspective:

Planetary exploration will be a thrust area of ISRO in the coming decades. Meteorite studies to understand the solar system objects forms the back bone for providing the scientific basis to understand the planetary formation and evolution processes and persons involved in such studies can participate and contribute significantly towards India's planetary science and exploration activities. In USA, Europe and Japan, most Universities and research institutes have research groups working on Meteotites and Planetary Science. In India, there are yet only a handful of places having interest in meteoritics. With a good collection of meteorites and a scope for further augmenting the collection, through systematic searches in hot (Thar) and cold (Himalayas) deserts, we need to take up efforts to encourage and enhance the community of meteoriticists in India. Though PLANEX has made a beginning in this direction, a more focussed and intense effort is needed for nucleating additional groups at Universities and National Research Institutes. Meteoritics and Planetary Science courses have to be included at B.Sc and M.Sc level for Geology students to make it a main stream subject. The samples of meteorites should be made available to deserving science projects through a fair and systematic process of sample request evaluation and curation. With GSI, Kolkata being the sole custodian of meteorites, that fall over Indian sub-continent this aspect needs improvement. A meteorite repository has to be coupled with an active meteorite research group for proper utilization, maintenance and curation/loaning of these precious samples. With the possibility of sample return missions by ISRO in near future, it would be a worthwhile idea to establish an additional facility for meteorite curation along with these returned samples, under the aegis of ISRO that will also have representative samples of the GSI collection as well.

Meteorites collected from Antarctica and the African and Australian deserts have yielded several new types of meteorites, providing an opportunity to study as yet unexplored solar system objects. It would be worthwhile to initiate meteorite searches in Thar desert and Himalayan cold deserts with the active involvement of institutes like Wadia Institute of Himalayan Geology, Dehradun, National Center for Antarctic and Ocean Research, Goa and Central Arid Zone Research Institute, Jodhpur etc. The topic of understanding the origin, evolution and extent of occurrence of life in the solar system is an exciting research area that is already getting lot of attention in the global scene. It is high time to focus on the study of organics in primitive meteorites and their relation to life. Living on this dynamic planet Earth, we can only hope to understand the formation and evolution of Earth as well as that of life on Earth through careful investigation of these "free space probes" which are the building blocks of our planet Earth. Meteorites still hold many secrets about our earth and other solar system bodies that are yet to be deciphered.

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