DHAJALA METEORITE

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Meteorites represent the earliest rocks formed in the solar system. It is even believed that all the planets are formed from meteorites, which are the first generation rocks. Thus, much before the rocks on the Earth, Moon or Mars recrystallised under the effects of volcanic events, heating or collisions with interplanetary bodies, the meteorites were formed, and they have remained in the same condition, more or less, ever since. Apart from mild erosion due to interplanetary radiation and dust and occasional collisions, little has happened to a large fraction of meteorites over billions of years, thus preserving the birth records of the solar system.

Meteorites arrive on the Earth by chance when their orbit crosses that of the Earth. In many ways, they are scientifically more valuable than moon rocks, coming from the farther reaches of the solar system. Meteorites contain more iron than earth or moon surface rocks. Concentration of iron shows distinct grouping in meteorites and generally stone meteorites are classified into LL, L and H groups representing Low-Low, Low and High iron content. Presence of round "chondrules" also distinguish them from earth rocks. A sub classification, going upto class 6 made first by Van Schmus and Wood (1967), represents progressively reheated bodies. The meteorites which have been not reheated (class 1 to 3) are most useful scientifically. The class 6 is completely homogenised and remelted whereas those belonging to class below 3 are unhomogeneous and chemically unequilibrated.

In this respect the great meteor shower of January 28, 1976, which fell in Gujarat around the village Dhajala is very interesting (Ballabh et al. 1976). It belongs to H3 group and is one of the few meteorites very thoroughly studied.

Fig. 1 shows the trail of meteorite against the background stars. It is generally believed that most of the meteorites are fragments of shattered asteroids and therefore their place of origin is between the orbits of Mars and Jupiter, while some other believe that they are the fragments of comets. For Dhajala meteoroid, we have assumed the asteroidal origin and have computed its orbit in space. Since the orbital velocity of the meteoroid is not precisely known, we assumed a range of velocities, the lower limit of which is the earth's escape velocity (11.7 km/sec) and the upper one being the limiting value (30 km/sec) for the total evaporation of the meteoroid in the atmosphere. From a variety of observations, particularly as the meteoroid showed high ablation ($\sim$90%), it could be ascertained that its geocentric velocity must have been between 20 and 25 km/sec.

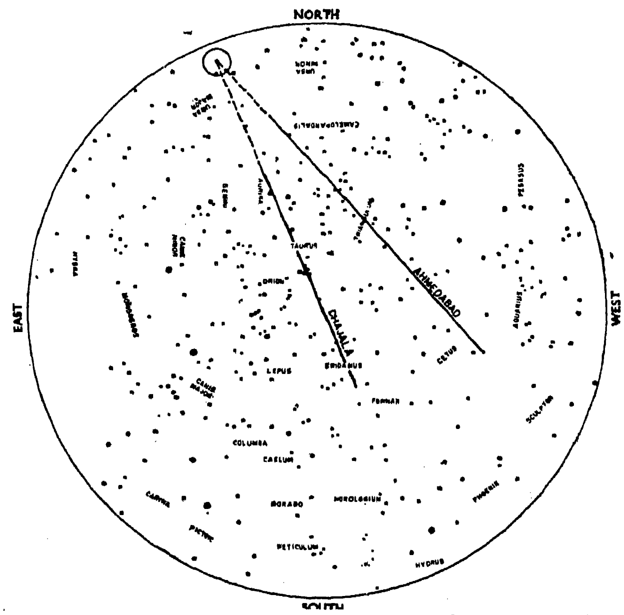

Fig. 1: Star map and the trails as seen from Ahmedabad and Dhajala are shown in the background of stars.

The orbital computations for this meteoroid show that it was moving in a prograde orbit (i.e. its sense of motion was the same as that of the earth) and that its heliocentric (assuming the Sun as the centre of the force) orbital velocity was higher than that of the Earth. Thus it came from behind and caught on with the Earth. The inclination of the orbit is 22$\pm$5° and is not so sensitive to the assumptions made.

One set of orbital parameters of Dhajala, probably the best choice, are shown in Table 1, together with those deduced for Pribram and Lost City meteorites where the velocity was photographically measured. Fig. 2 shows the computed orbit of Dhajala in its orbital plane. It must however be mentioned that if the velocity is higher, a cometary orbit cannot be excluded.

More than 60 kg of stones distributed over 500 fragments have been found scattered over a long elliptical zone. The strewn field shows many interesting features. These have been discussed in detail by Bhandari et al (1976) and Lal and Trivedi (1977). As one follows the direction of travel of the meteorites from Khintla to Ninama, we found bigger and bigger stones, starting from a few grams at the beginning to about 12 kg at the end of this strewn field. Not only the size systematically increased along the fallout track, the number of stones along the strewn field decreased (Fig. 3).

TABLE 1

A comparison of orbital parameters of meteorites

	True RA	Radiant DEC	V∞ km/sec	a a.u.	e	q	q′	i
Dhajala	156°.7	+59°.4	21.5	1.80	0.59	0.73	2.84	27°.6
Pribram	191°.5	+17.7	20.9	2.42	0.67	0.79	4.0	10°
Lost City	135°	+39.1	14.2	1.88	0.41	0.96	1.3	12°

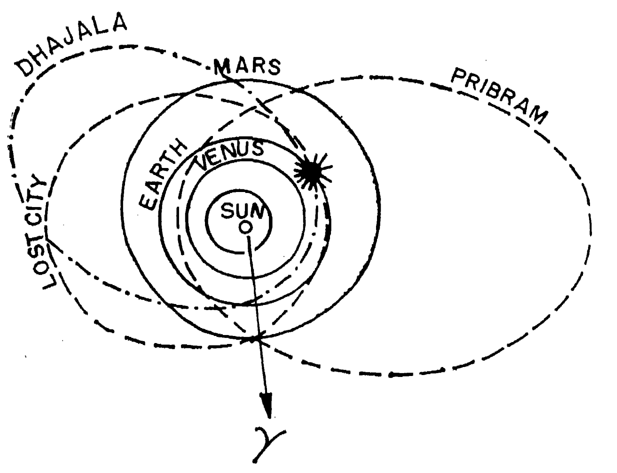

Fig. 2: The orbit of the Dhajala meteorite possibly lay between Venus and Jupiter. For comparison, two well known orbits of meteorites, Pribram and Lost City, are also shown.

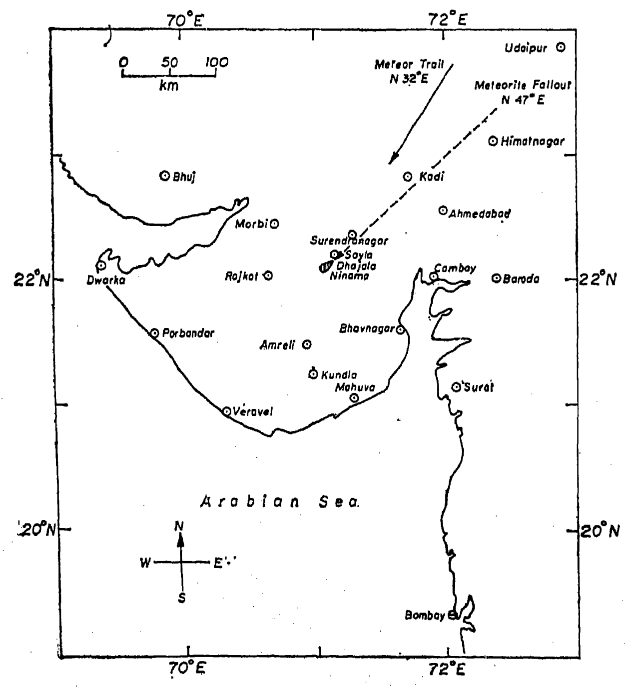

Fig. 3 (a): Geographical location of the meteroritic fallout. Direction of meteorite trail is also shown.

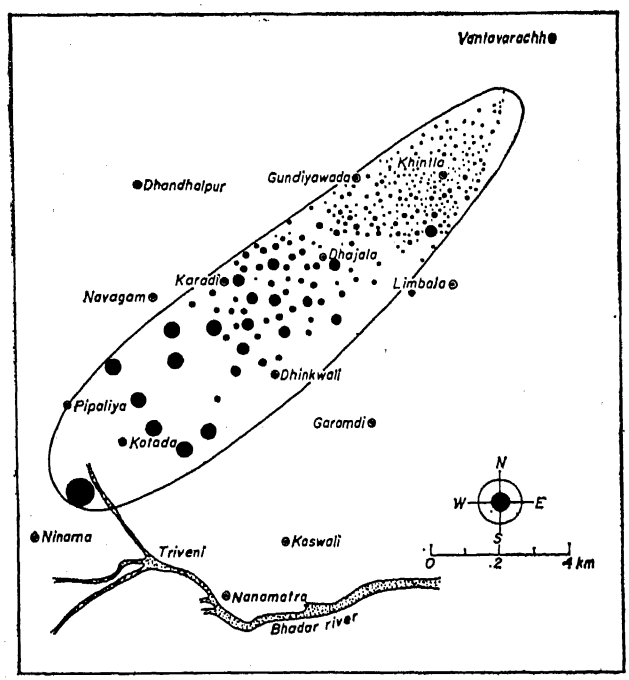

Fig. 3 (b): Fallout pattern of stones. The dots represent frangments distributed in a large (18 km long) elliptical zone, shown as a function of their size (after Lal & Trivedi 1977). The largest stone, recovered at the end of the trail weighing about 12 kg was found in a shallow crater.

Several investigations on the recovered meteorite fragments have been carried out. Mr. M.M. Sarin at the Physical Research Laboratory, carried out a systematic chemical analysis and showed that the meteorite can be classifed as a High Iron (H) group chondrite. The chemcial composition of this meteorite is Fe: 28.6%, Mg: 13%, Ni: 1.7%, Ca: 1.5%, Al: 1.1%, Na: 0.6%, Cr: 0.21%, Mn: 0.2%, P: 1.5% and K and Co 800 ppm (parts per million) each. Apart from this analysis based on atomic absorption spectrophotometry, Dr. M. Sankar Das of Bhabha Atomic Research Centre has carried out a sensitive chemical analysis using neutron activation technique. Trace elements such as rare earths, and heavy elements have been studied by them. A mineralogic petrographic analysis by Dr. G.V.U. Rao of BARC showed a high abundance of pyroxenes 42.1% (mainly bronzites), olivines 28.6%, troilite 5% and Ni-Fe phases 19.5% in this meteorite. Mr. V.G. Shah of PRL made a systematic chemical analysis of minerals and studied their structure under scanning electron microscope. On these analyses, it was found that various phases in this meteorite are not under chemical equilibirum. Some of these pictures are shown in figures 4 and 5. The meteorite has a preponderance of chondrules and they range in size from a few tens of microns to over 5 mm. The biggest chondrule about 5 mm in size is shown in fig. 6. Apart from these features, the meteorite contains a large number of inclusions. A centimetre size enstatite inclusion containing feldspathic flaky crystal growths is shown in Fig. 7. How these inclusions and chondrules are formed is a big mystery. The temperature and pressure conditions necessary to form such a large inclusion would lead to an idea about the formation environment of primitive objects in the solar system.

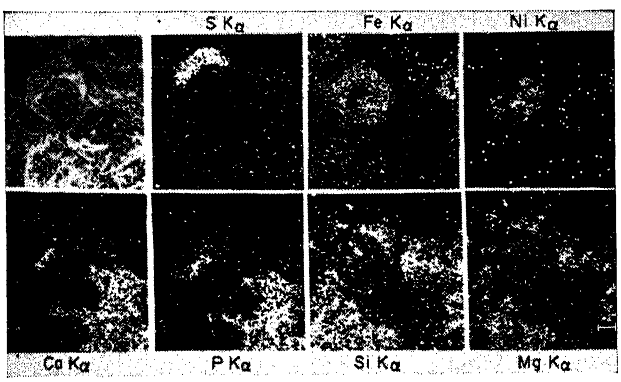

Fig. 4 : Scanning electron micrographs of a Dhajala chondrule showing distribution of elements in their characteristic x-ray images : sulphur, iron, nickel, calcium, phosphorus, silicon and magnesium. Presence of troilite, apatite, olivine and Ni-Fe phases can be deduced from these analyses. The non-homogeneous distributions show that the meteorite is unequilibrated and primitive.

Cosmic Ray Effects :

Cosmic ray effects tell much about the history of the meteorite in interplanetary space. The K-Ar age of the meteorite as determined by Prof. M.N. Rao and his colleagues at PRL is 4.2±0.2 billion years indicates that the meteorite was formed in the earliest epochs of the solar system The exposure age to cosmic rays however is only 6 million years (Gopalan et al. 1977), suggesting that the meteorite lay shielded all through its life except that for the last 6 million years it was exposed to galactic cosmic rays in the interplanetary space before finally it fell on the Earth.

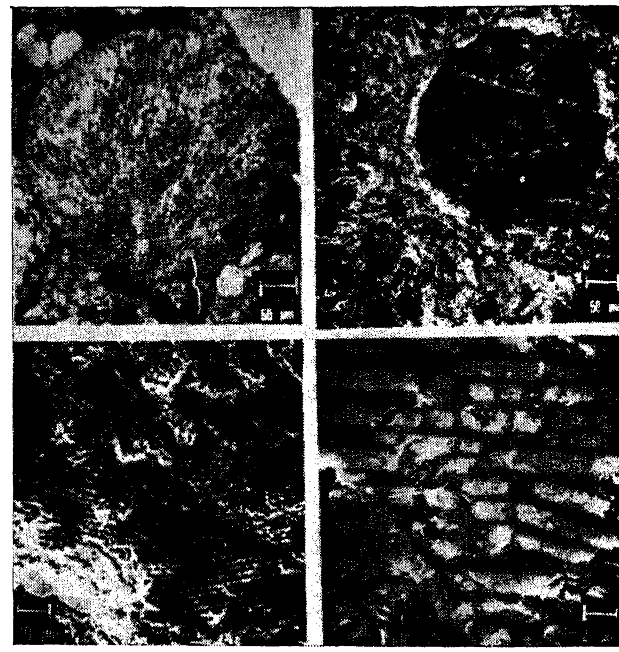

Fig. 5 : A variety of chondrules seen in Dhajala-above an eccentrically radiating chondrule and a rimmed chondrule. The lower two pictures are successive enlargements of the second chondrule showing a brick-work of minreals (feldspar), sub-micron to micron size-arranged in an array (Photo : V.G. Shah).

Fig. 6 : Dhajala has an abundance of chondrules. Picture shows the largest chondrule seen so far, about 5 mm in diameter.

Fig. 7 : A large centimeter size inclusion of Dhajala, containing flaky crystals, appearing as a crescent moon in the picture. Chemical analysis of inclusion shows presence of Si, Mg, Fe and Ca in decreasing order of abundance. The major mineral present is enstatite, but feldspars, olivine, chromite and apatite have also been detected.

The track analyses carried out by Prof. D. Lal and his colleagues at PRL show a variety of interesting phenomena- the dynamics of fragmentations and ablation. They found that in such a catastrophic fragmentation as in Dhajala, which borke into 450 fragments, pieces from all through the body of the meteorite survive. They estimate a mass of about a ton for the meteorite body in space before it entered the earth's atmosphere. Thus more than 900 kg of the material was evaported in the atmosphere and only about 60 kg survived. A very systematic work on fragmentation mechanics and size distribution of fragments has been carried out by Lal and Trivedi on this meteorite.

An interesting result has come out from the study of radionuclides in this meteorite. Firstly due to its quick recovery, a large number of isotopes could be studied which is normally very difficult. These isotopes ranged in half-life from 5.5 day ^{52}Mn to 3.7 million years ^{53}Mn. A concentration higher than expected for ^{54}Mn and ^{57}Co indicates a somewhat higher flux of galactic cosmic rays at higher heliolatitudes in the space covered by the orbit of the Dhajala meteorite.

The Dhajala meteorite has turned out to be one of the few unequilibrated chondrites and it is hoped that a more detailed work will lead us to new insights into cosmochemical conditions of the beginning stages of the solar sytem.

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