Skylab Isn't All That's Falling

Seventy-one years ago a boulder weighing a million tons fell from space into the earth's atmosphere, destroying two thousand square kilometers of Siberian forest. Recent research shows that encounters with similar meter- to kilometer-sized boulders are surprisingly frequent, but few of these objects reach the ground intact.

BY KEITH HINDLEY

The huge volume of space between the terrestrial planets teems with debris. Hundreds of kilometer-sized asteroids rub shoulders with billions of meter-sized boulders which in turn plough their way through a dense cloud of dust particles. Mutual collisions are commonplace. The earth itself sweeps up well over 100,000 tons of such debris each year, including many large boulders. The earth's surface carries the scars of these encounters in an ever-lengthening list of meteorite impact craters. Yet only a tiny proportion of this infall of boulders survives its passage through the atmosphere to mark the surface. The bulk are powdered high in the atmosphere to blanket each square kilometer of the surface with a hundred grams of fine dust each year.

Direct evidence of large bodies comes from studies of comets and asteroids. Although the passage of one of these bodies close to the earth does occasionally make the headlines, such events are far more common than is generally supposed. During the period from 1975 to 1978, a kilometer-sized comet nucleus and three or four similar sized asteroids annually passed within 30 million kilometers (about 80 moon distances) of the earth. Ninety-one such encounters have been recorded since 1680. Passages by comets have occurred with remarkable regularity. In contrast, the number of known close passages by Apollo and Amor class asteroids (the former move in toward the sun and cross over the earth's orbit, the latter approach close to the earth's orbit) have grown steadily in the last fifty years. Yet these discovered passages are the tip of the iceberg. The coverage by astronomical cameras is sporadic, and they probably record fewer than one in twenty passages. There may be a thousand asteroids of one kilometer or larger milling around the terrestrial planets. At any time, even as you read this, there are likely to be one or two of these within 30 million kilometers of the earth in the process of swinging past.

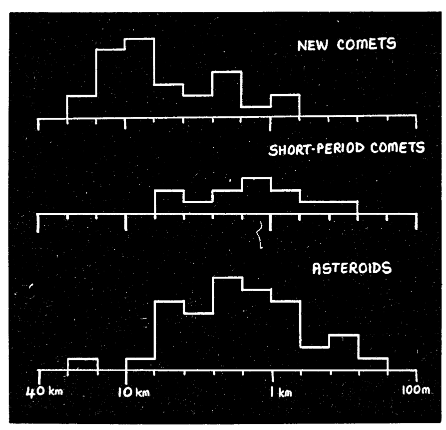
The asteroid Hermes holds the record for closest approach, passing within three-quarters of a million kilometers in 1937, only twice the distance of the moon. Statistics suggest that collisions probably occur at roughly 200,000-year intervals. While this is a comforting interval, it is a short period geologically. It suggests, for example, that more than two thousand asteroid-earth collisions have occurred in the 600 million years since the start of the Cambrian geological era. A one-kilometer asteroid produces a 100,000-megaton explosion on surface impact as its vast energy of motion is converted almost instantly into heat. The resulting explosion digs a twenty-kilometer-diameter crater and can affect an area of millions of square kilometers. Currently, 96 such impact sites have now been recognized worldwide by the severe shock effects in the rocks of the now weathered remains of ancient craters.

The size distribution of the passing comets and asteroids reveals some interesting details. It is clear that new comets, relatively bright objects traveling in highly elongated ellipses moving right out to the edges of the solar system, have a cutoff in their nucleus size at about 1 kilometer. A small active comet nucleus set in a cloud of glowing gas should be easier to spot than a small dark asteroid, yet none have been found. In contrast, short period comet nuclei are smaller in size, as befits their supposed origin as new comets captured into short period orbits and rapidly stripped of their outer layers by repeated close approaches to the sun. The Apollo and Amor asteroids include very many small objects, underlining the likelihood that they are mainly the degassed remains or fragments of ancient periodic comet nuclei.

The smallest asteroid recorded to date is a 200-meter-diameter object which swept past in October 1976. This is close to the size of object that has produced several major meteoritic events in recent history. The Arizona meteor crater is a one-kilometer-diameter bowl produced about 22,000 years ago by a 100,000-ton, 25-meter-diameter iron meteorite impacting in the Arizona desert at about 10 km/sec. This iron body survived passage through the atmosphere intact and struck the surface with a major portion of its original cosmic velocity. This behavior is found to be untypical, however. There are two other examples of craters produced by iron masses of about this size. In these, however, the iron body fragmented late during its atmospheric flight. In each case, this produced a shower of small iron-rich fragments and only a scattered field of small craters. The only witnessed event of this kind occurred in February 1947 when a hundred-ton, 3-meter-diameter iron boulder entered the atmosphere over the Skhote Alin mountains in the eastern Soviet Union. A dazzling daylight fireball fragmented into a shower of debris to produce a field of small craters and a scattering of iron meteorites.

In the majority of cases where iron or stony-iron meteorites are associated with craters, it is a field of small craters rather than a single large bowl that has been produced. It is certainly significant that no stony meteorites have been found associated with major meteorite craters. It seems that meter-sized boulders of practically all meteorite types except some irons and stony-irons are broken up into fragments on entry into the earth's atmosphere.

Direct information about material present in these boulders has come from the various fireball photography networks (arrays of unmanned camera stations that automatically record the light of incoming fireballs). These have been photographing millions of square kilometers of the atmosphere over the United States, Canada, Britain, Germany and Czechoslovakia for fifteen years. They have recorded the entry of objects up to 5 meters across and weighing several hundred tons. Analyses of the results suggest that the boulders consist of almost equal proportions of three types of material. First are a group of hard stony objects that can be identified with the ordinary stone meteorites. Sec-

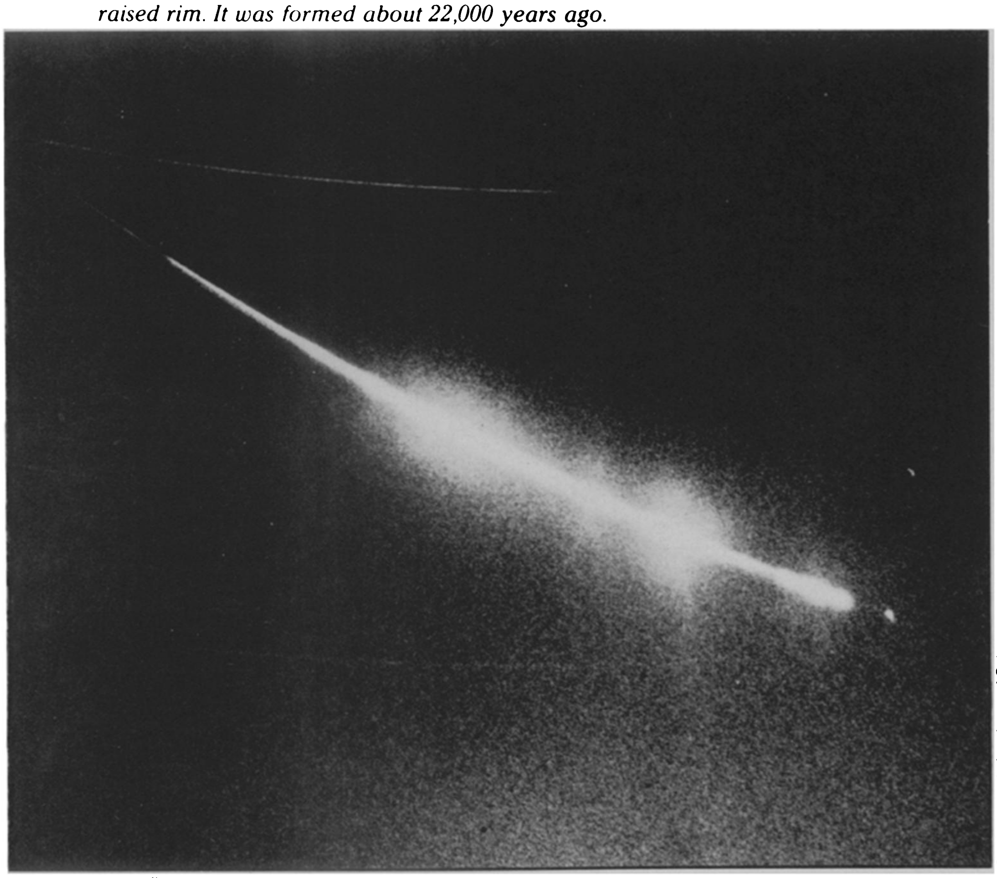


Hindley

The size distribution of comets and asteroids passing close to the earth. There is a notable lack of small new comets, while small periodic comets and asteroids abound.

Keith Hindley, a freelance science writer in York, England, is director of operations for the British portion of the European Fireball Network.

The Arizona meteor crater is a 1.2-km-diameter, 180-meter-deep impact bowl with a raised rim. It was formed about 22,000 years ago.



Czechoslovak Academy of Sciences

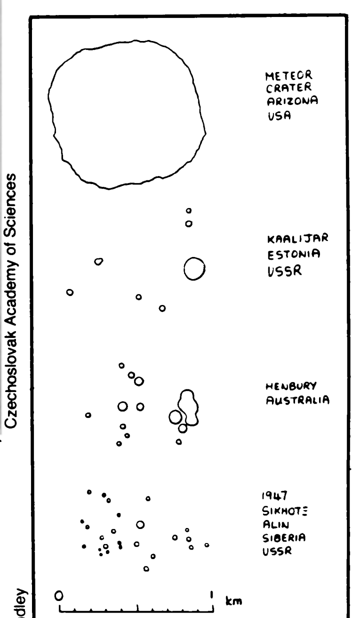
The Šumava fireball of December 1974. A 200-ton boulder was destroyed in a series of brilliant flashes, each 500 times brighter than the full moon. The trail was recorded on a time exposure and is curved by the wide-angle optics of an 11-sky fireball camera.

ond are a group composed of more fragile material similar to the carbonaceous stone meteorites. The final group is composed of two types of very friable cometary material. Iron and stony-iron meteorites do not figure at all and must occur in far fewer than one in a hundred natural space boulders. The networks show that almost all large rocks are powdered during entry, with only a handful surviving after breakup into slow-moving showers of gram-, kilogram- and occasionally ton-sized meteorites.

These results help in understanding the true nature of the most dramatic meteoric event of this century—the great Tunguska fireball of 1908. On June 30 of that year, a dazzling fireball that locally appeared brighter than the sun descended into the atmosphere over central Siberia. It suffered a blinding terminal flare at about 6 km height, and the shock wave from its arrival flattened about 2,000 square kilometers of forest. Surprisingly, no craters were ever found, and it is clear that the whole body disintegrated in the terminal flare. This feature of the fall has led practically every authority to conclude that the body was extremely fragile. The trajectory it followed is believed to have come from an orbit around the sun almost identical with that of periodic comet Encke. Some researchers conclude that the Tunguska boulder was almost certainly debris from this comet.

Unfortunately, penetration down to a height of only 6 km is not the behavior of a weak fragile body. A good example of how this type of fragile material does behave is given by the Šumava fireball, which was recorded by the Czechoslovak network in December 1974. This 200-ton boulder entered at 26 km/sec but completely destroyed itself in just over three seconds. The major flares, marking where the body crumbled, occurred between 73 km and 61 km, and only a small piece penetrated down to 55 km.

One fireball recorded by the Smithsonian's Prairie Network in the United States did produce some features in common with Tunguska. This was the Ozarks fireball of October 1969. This 35-ton body entered at 21 km/sec and descended to an altitude of only 22 km above the ground where it suffered massive disintegration in two brilliant terminal flares. In each of these flashes an estimated six tons of quite hard carbonaceous stone was destroyed almost instantly. These terminal flares were similar in type to that for the Tunguska object, and the fireball even pro-



Hindley

The Arizona, Kaalijarv and Henbury craters were all produced by the entry of iron masses of about 100,000 tons. The only witnessed event of this type is shown at bottom, where a 100-ton iron body disintegrated in flight to form a scattering of small craters.

duced strong shock waves heard widely as a series of intense sonic booms. The similarities to Tunguska are clear.

The Tunguska body, however, is believed to have entered at about 31 km/sec and penetrated down to only 6 km. There the aerodynamic pressure on it was thirty times greater than that which destroyed the Ozarks body. Clearly this behavior is inconsistent with any type of fragile cometary material and is difficult to reconcile with even hard carbonaceous stone. The Tunguska body is most likely to have been composed of relatively hard stony material possibly akin to the ordinary chondrite meteorites. The terminal flare that so effectively destroyed the main mass can be explained by the massive catastrophic disintegration of the body into a huge cloud of gram, kilogram and perhaps even larger pieces.

Similar disintegration of ton-sized stony bodies in flight is common. In the case of Tunguska, the boulder probably disintegrated at 12 to 14 km/sec at a height where the fragments were scorched by air more than 100,000 times denser than that which would easily have destroyed them individually at normal meteor heights had each entered alone. The cloud of fragments would be melted and vaporized almost instantly to produce the brilliant terminal flash which singed the clothes of witnesses 60 km away. The result of the flare was a dense cloud of iron and silicate spherules, the condensed remains of the vaporized boulder, which still abound in the local soil today.

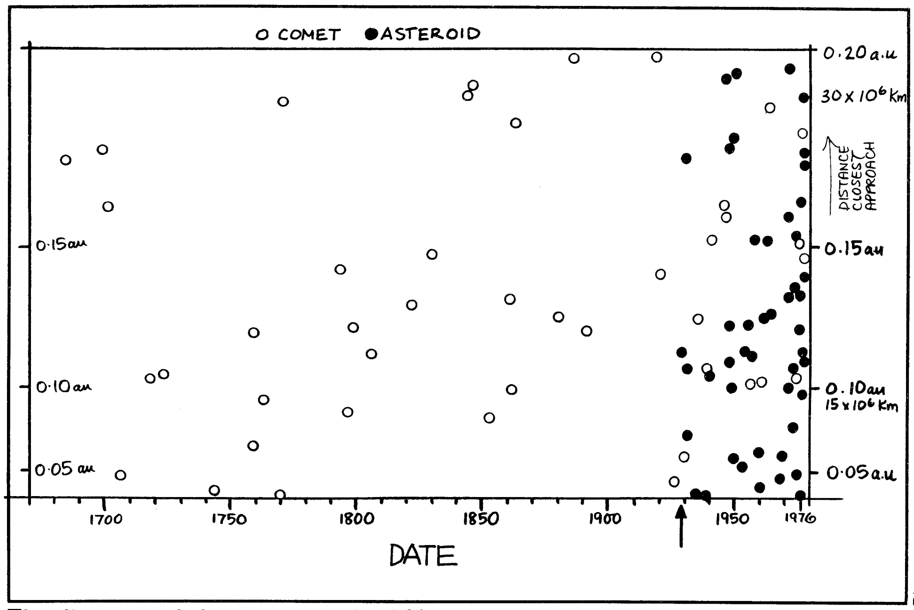
It seems that the great majority of stony bodies of all boulder types in the 100-meter size range will produce a Tunguska-type event with its accompanying surface destruction. The formation of a crater by the rare iron or stoney-iron strong enough to survive infall intact would occur in far fewer than one in a thousand events. It may well be that for larger objects in the kilometer-size range, the harder stony material might make it down to the ground, but the objects would then leave no trace of their nature. All giant objects of this size would be completely vaporized by the impact explosion.

The results from these studies of asteroids, comets and fireballs furnish statistics about encounters with space debris. It is estimated that a 100-ton body enters the earth's atmosphere every day, a 1,000-ton body once a month, a 15,000-ton boulder once a year and a 100,000-ton object once a decade. A million-ton boulder in the Tunguska class enters once every century or two, but irons are so rare that meteorite craters are formed only once every few tens of thousands of years.

It should be possible to locate a few of the most recent Tunguska-style events from signs of their 50-km-diameter zones of ground devastation, especially in forest areas. One possible site is suggested by an intriguing entry discovered recently in the London Penny magazine for 1834. It recounts how, "in the progress of draining the Isle of Axholme in Lincolnshire, evidence has everywhere been found not only of previous vegetation but that this spot must have been suddenly overwhelmed by some violent convulsion of nature. Great numbers of oak, fir and other trees were found lying 5 feet underground." The tree trunks were all aligned in a northwest direction and had not been "dissevered by the axe but had been burnt asunder near the ground, the ends still presenting a charred surface." The similarity of this description with the scenes of razed forest in the Tunguska blast area is striking. Perhaps this area of England suffered a Tunguska-style event just a few millennia ago.

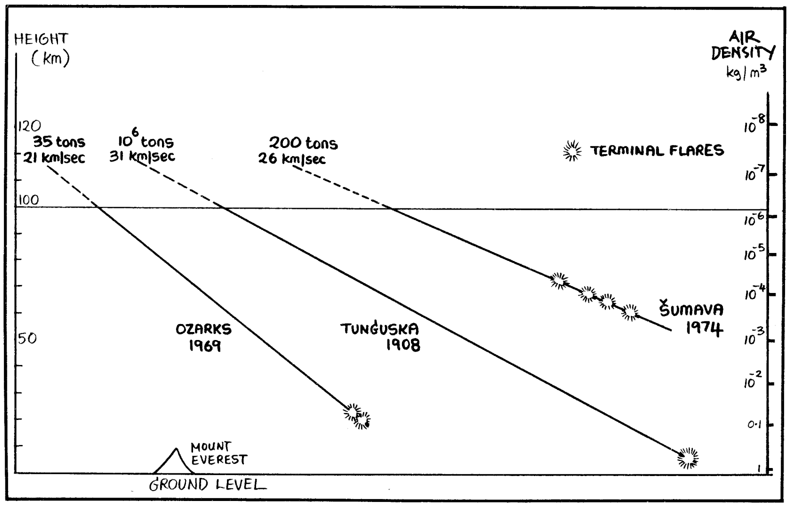
Our greatest risk undoubtedly comes from further fragments of periodic comet Encke. This remarkable comet has distributed more dust and larger debris around the inner solar system in recent millennia than all other comets combined. Each year the earth ploughs through the heart of this material twice to produce the Taurid meteor shower in October and November and the B-Taurids in June and July. Both these showers contain a higher-than-usual proportion of larger bodies up to kilometer size. Further evidence of larger bodies comes from the lunar seismic experiments left on the moon by the Apollo missions. These have recorded the impact of many space boulders and it may be significant that about half of the largest lunar meteoroid impacts have occurred during the June to July period when we pass through the main debris from comet Encke. It is then that we are at greatest risk of another Tunguska event.

Although we are statistically safe from a crater-producing impact for quite a long time, there is a good chance that another Tunguska-style event will occur within the next century. It is most likely to occur safely over one of the oceans, but could occur with devastating results over populated areas. It is most unlikely that the boulder concerned will be detected before collision, and so the brilliant entry fireball will appear quite unexpectedly. □



Diagrams: Hindley

The distances of closest approach of 91 recorded comet and asteroid encounters are plotted here. The logarithmic scale vertically would give a uniform scatter of points for random encounters. Apollo and Amor asteroids (arrow) were not discovered until 1929.



The entry fireballs of three recent large interplanetary boulders showing their depth of penetration before being destroyed.