Rocks from space

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Introduction

Over its history the Earth has been affected by the impact of bodies from space. What these bodies are, how they have been formed, the features of the resulting impact craters and how the latter differ from volcanic is the subject of this lecture.

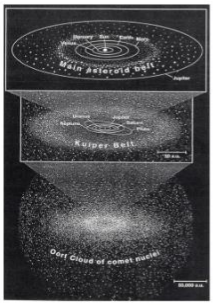
Impact Earth

What bodies can impact our planet?

How have those bodies formed?

What are the features of impact craters?

How can we differentiate them from volcanic craters?



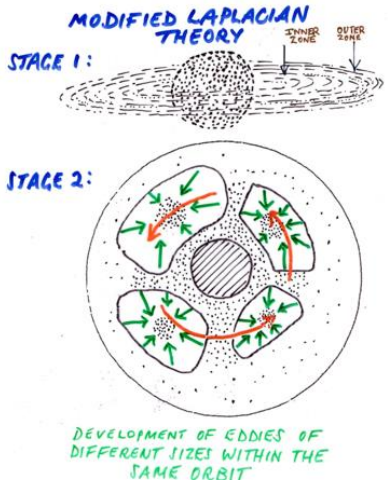
Objects that can impact our planet

- Asteroids on 'earth crossing' orbits
- Asteroid fragments from collisions within asteroid belt
- Comets including 'burnt out' remnants
- Cometary fragments – fragmentation due to close approach to Sun
- Planetismals and their fragments caused by orbital collisions

Formation

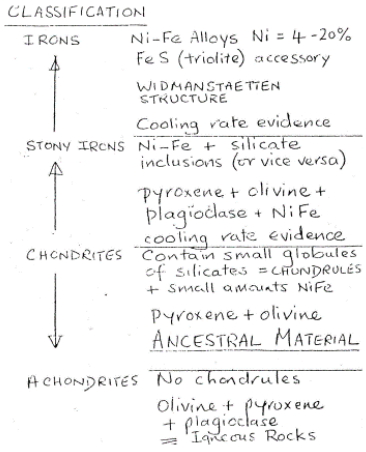
The early solar system (4.5Ga) developed through the cold accretion of dust, gravity pulling it together, heating up to form the Sun (99% of the mass of the Solar System). The planets developed as dust coagulated forming eddies that, in turn, absorbed smaller bodies and under gravity coalesced into solid bodies. Some remained free and formed asteroids. Ultima Thule, recently photographed by the New Horizons spacecraft (see below) is an example of a body, in the Kuiper Belt, that formed through cold accretion.

The Early Solar System



Types of meteorite

Meteorites are classified into three main types: Achondrites, Chondrites and Irons



Irons - Composition similar to core

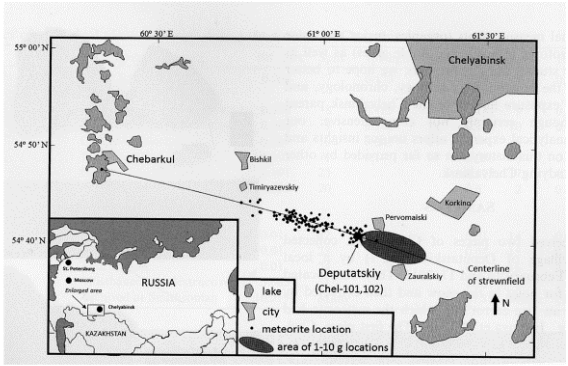
Stony Irons – Between mantle and core

Chondrites – Unmodified, unseparated ancestral material. Contain whole periodic table. Subsequently some involved with plantesimals to form cores (Irons) and mantles (Achondrites).

Achondrites – Composition similar to mantle

Chelyabinsk - 2013

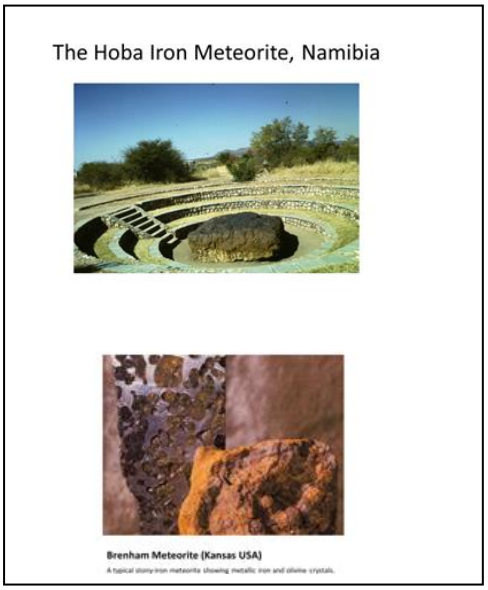
Chondritic meteorite that exploded in the atmosphere, creating a large shock wave and showering Chelyabinsk with a trail of debris.



Iron - Hoba Meteorite (Namibia) and Agpalilik (Greenland)

Weighing c60 tons, Hoba is comprised of iron (84%) and nickel (16%). There is no impact crater as it hit the earth's atmosphere at a low angle slowed and fell under gravity. (also described was the Agpalilik meteorite found in Greeenland and now outside the Geological Musuem, Copenhagen.

Brenham Meteorite – rare stoney-iron meteorite from core mantle border of planetismal.



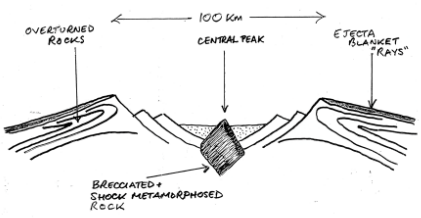
Comets

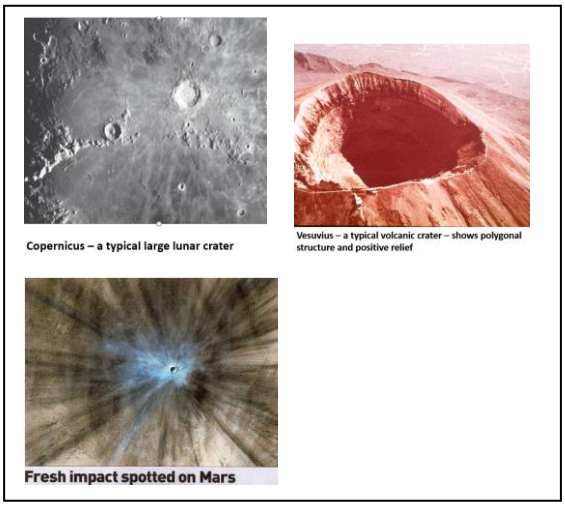
Comets are made of dust, ice and gas. Their orbit decays as they move in and out of the solar system and the larger planets (eg Jupiter), with a huge gravitational pull, tend to attract comets in preference to the smaller planets such as the Earth. The Shoemaker-Levy 9 comet which impacted Jupiter in 1994 was pulled into 12 parts, each with an average size equivalent to that of the Earth.

Features of impact craters

Impact craters are essentially circular. The impact vaporises material and throws out a circular blanket of ejecta, the shape of which, is only slightly affected by the angle of impact. (eg Mars Crater). As the surface rocks are impacted and vaporised, they are pushed back and overturned near the rim (like opening a sardine can), the sides fall in and eventually the centre rebounds forming a peak in the centre. In contrast, volcanic craters are not usually circular and are positive features (unlike meteorite craters where the approach is flat).

Features of an impact crater





Craters are much larger than the body that causes them. For example, the Barringer Crater in Arizona (c1mile across) was created by a body the size of a telephone box. The rocks at

The scale of the impactor

METEORITIC IMPACT ON THE EARTH

ENERGY (Megatons)	DIAMETER IMPACTOR (km)	INTERVAL (Years)	EXAMPLE
10^{-2}	0.007	0.5	
10	0.07	200	Barringer Meteor *
10^5	1.4	3×10^5	Ries (Germa
10^8	14	9×10^7	K-T event (Chicxulub: Mexico)

NOTES: 1 Megaton = Energy released by explosion of 1 million tons of TNT

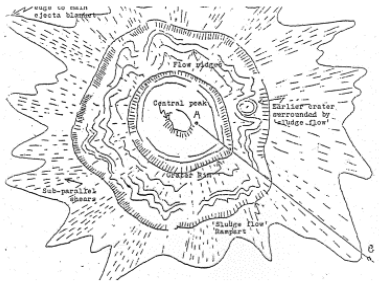
SOME EXAMPLES for comparison:
KRAKATOA (1883) 50 Megatons Energy
HIROSHIMA Atomic Bomb 1/50 Megaton

* Impactors of this diameter often fragment in atmosphere.

the rim are folded and over-turned, fragments of the meteorite are found in the ejecta around the crater (but not in it).

Mars

Smaller than the Earth, Mars attracts fewer bodies. It has a permafrost layer below the surface and, as a result, the impact craters may also have a sludge flow.



Impact on Mars – Arandas crater (28 km across)

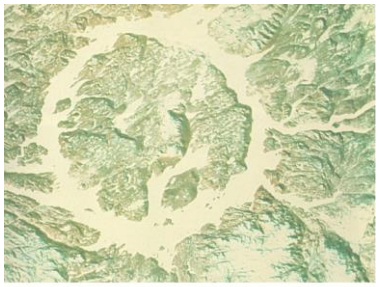
Impact into sub-surface permafrost has generated melting and subsequent mass movement of material as sludge flows . The flowing material has moved around a pre-existing impact crater.

Some meteorites, found in Antarctica, are believed to have originated as ejecta from impacts on Mars (on the basis of their mineralogical composition and that of trapped gas, which is, similar to the Martian atmosphere). Calcium carbonate structures seen in these meteorites, originally thought to be organic, are now interpreted as the result of chemical precipitation.

First 100Ma of the Earth

100 Ma the Earth-Moon system was formed by a glancing impact on the Earth of a body slightly smaller than Mars. The impactor's core coalesced with the molten Earth and its mantle. Some of the mantle of the Earth and of the impactor was flung into space as an orbiting debris cloud which eventually coalesced to form the Moon.

Craters – Manicougan Crater - Canadian Shield



Manicouagan Crater, Canada (210 Ma)

This is now heavily eroded and all that is left is the structure formed within the Precambrian basement of the Canadian Shield. Note the central elevation caused by decompression after the event .

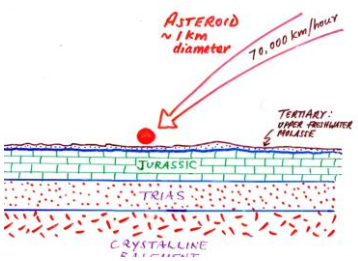
Now heavily eroded, all that is left is the structure formed within the Precambrian basement of the Canadian Shield. Note the central elevation caused by decompression after the event.

Craters – Ries Crater , Southern Germany

The Ries Crater, Southern Germany

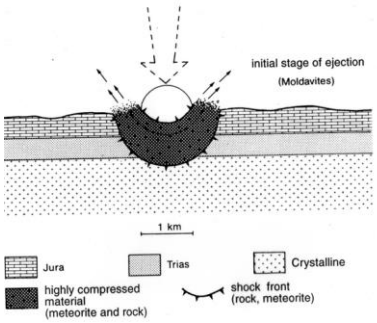
- Impact of a 1 km diameter asteroid – about the size of the walled old town of Nordlingen which sits in the crater
- Took place in Miocene times (16 Ma)
- Crater thought to be volcanic on earlier analyses
- Associated with the smaller crater of Steinheim to the west

The Impact Event

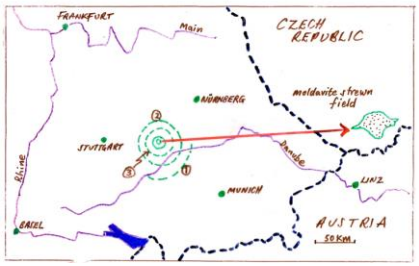


Meteorite impact excavated rocks down to the basement

Initial impact



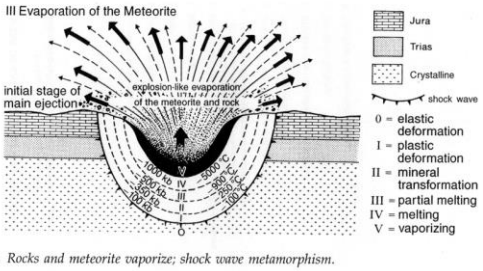
A blizzard of tectites



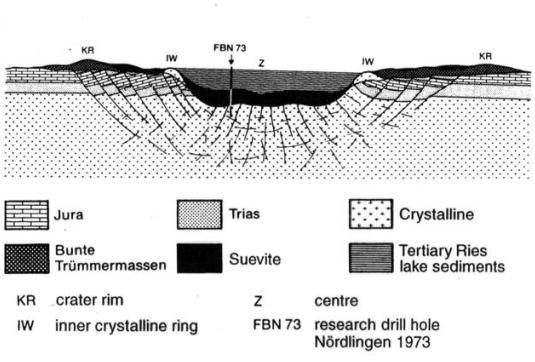
The whole area formed within 1 second of impact. Throwing material (tectites - green glass) 250km to the east into Czechia. Implies the meteorite came from the west at a low angle.

Final Ries crater profile

The excavation of the Ries crater



Phase 3. Rocks and meteorite vaporize; shock wave metamorphism.



The huge pressures and shock wave excavated the crater, throwing the local rocks outwards as a blanket and molten material upwards in a huge fireball. The pressures were sufficient to form small diamonds and the shock wave creates shatter cones in the local rocks. (Note, diamonds are found in big impact craters including Sudbury, Canada, the location of a large mine for the extraction of meteoric nickel.)

After the event, the crater comprised a fractured basement overlain by Suevite (black molten impact material, like an ignimbrite with fragments of molten glass) within the inner ring of the crater. Further out, the blocks of limestone and Trias thrown out first (up to 30km) by the impact are also overlain by Suevite from the fireball (see below right).

Steinheim Village

Crater rim in the background with central peak rising to the left just beyond the houses.

The occurrence of suevite and the Bunte Breccia

Tunguska Event

Tunguska Impact

- Event took place on 30th June 1908
- Effects felt and seen in Great Britain to the west and in Japan to the east
- Impact site not visited until 1921-1922 and not extensively researched until 1927
- 30 million levelled trees in butterfly-shaped blast zone but no crater
- A 'telegraph pole forest' in the centre of the blast zone

Map of the Blast Area

Thought to have been an explosion, 6-8km above Siberia, caused by a complex shaped body (implied by the butterfly shaped blast area) entering the atmosphere with a slow, low trajectory. The blast effect suggests a body no more than 10,000 tons. The development of scabs on reindeer and rapid tree growth suggest nuclear radiation from the explosion.

Possibly two bodies involved, only one exploded, the other one escaped. Features observed include rare earth elements, radiation effects and a geomagnetic storm. Cometary impact seems the most likely cause but that does not explain everything (ie rare earth elements).

Mass extinction event - End of Cretaceous / K-T boundary

The last day of the Cretaceous

- Mass extinction at the end of the Cretaceous
- Extinction of the dinosaurs and of many invertebrate groups (eg ammonites)
- Study of K-T boundary reveals strong iridium anomaly which would result from vaporising asteroid impact
- Where was the 'Smoking gun'?
- Could there be alternative explanations?

The K-T event

Asteroid Impact

- Explains iridium anomaly and its narrow occurrence in both Europe and in the United States
- Explains related tsunami-generated horizons
- Chicxulub crater in Mexico is in the right place, is of the right age, and is big enough to cause a worldwide mass extinction event

Deccan Volcanism

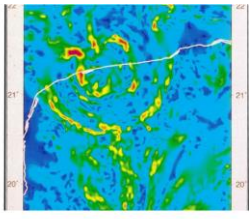
- Vast outpourings of basalt lavas over 5 Ma
- Would have major effect on climate with increasing sulphur dioxide and carbon dioxide
- Blocking out of Sun's radiation would destroy photosynthesis and dependent plant life

At this time there was an asteroid impact at Chixulub, Mexico and the Deccan volcanism. They may be related with the shock wave triggering the volcanism.

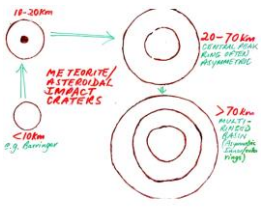
Mass extinction events

A number of Large Igneous Province occurrences and Mass extinction events and such as the Columbia River (Miocene16Ma), Deccan (K/T 63Ma) and Siberian(Permian/Triassic 251Ma) appear to be associated with meteorite impacts of similar age.

Impacts



Gravity anomaly map showing double ring structure seen at Chixulub in the Yucatan beneath younger sedimentary sequences



Different size impactors and their resultant craters

Larger the impactor the higher the number of rings.