METEOROIDS, METEORITES and IMPACT CRATERS

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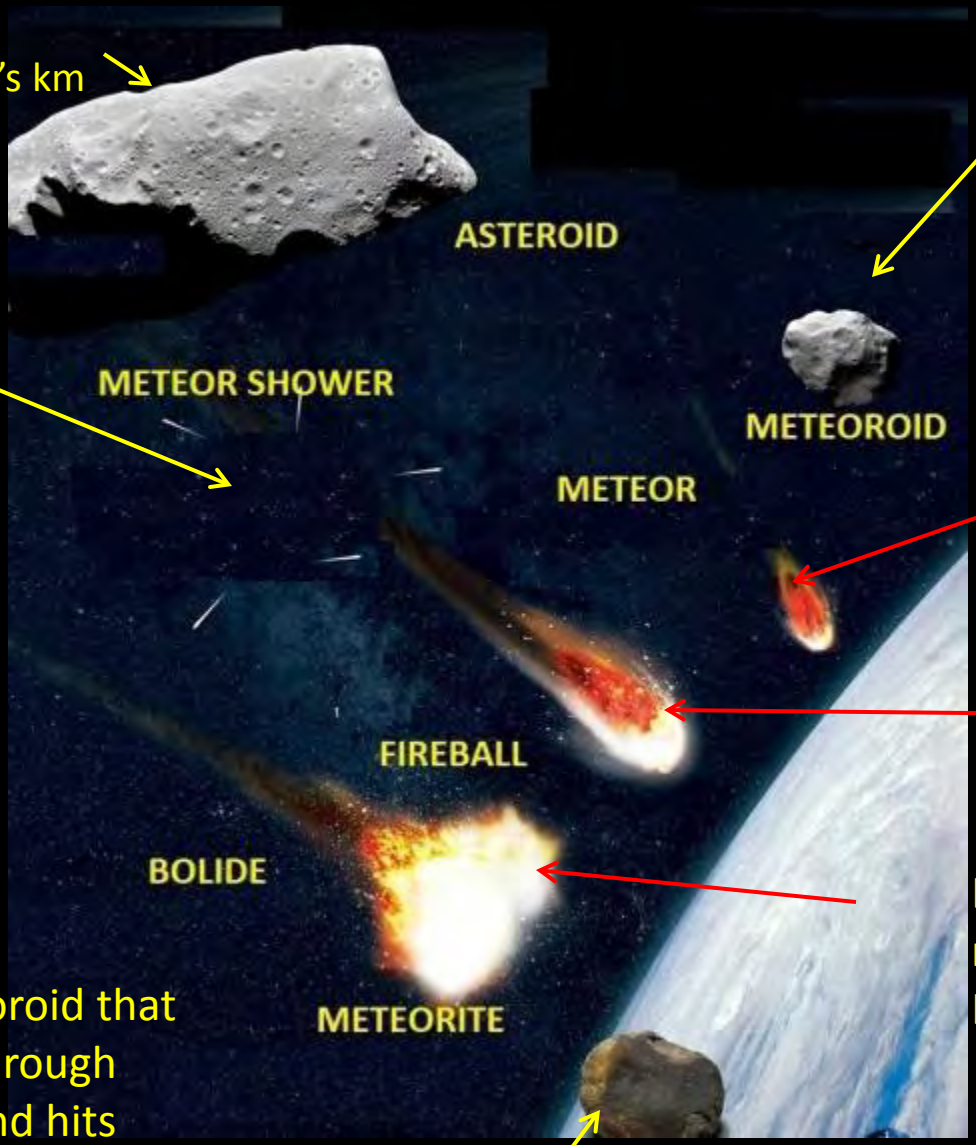
TERMINOLOGY

Rocky, iron or icy debris flying in space, 1 m to 100's km



A small asteroid, from microns to few meters.

Annual events

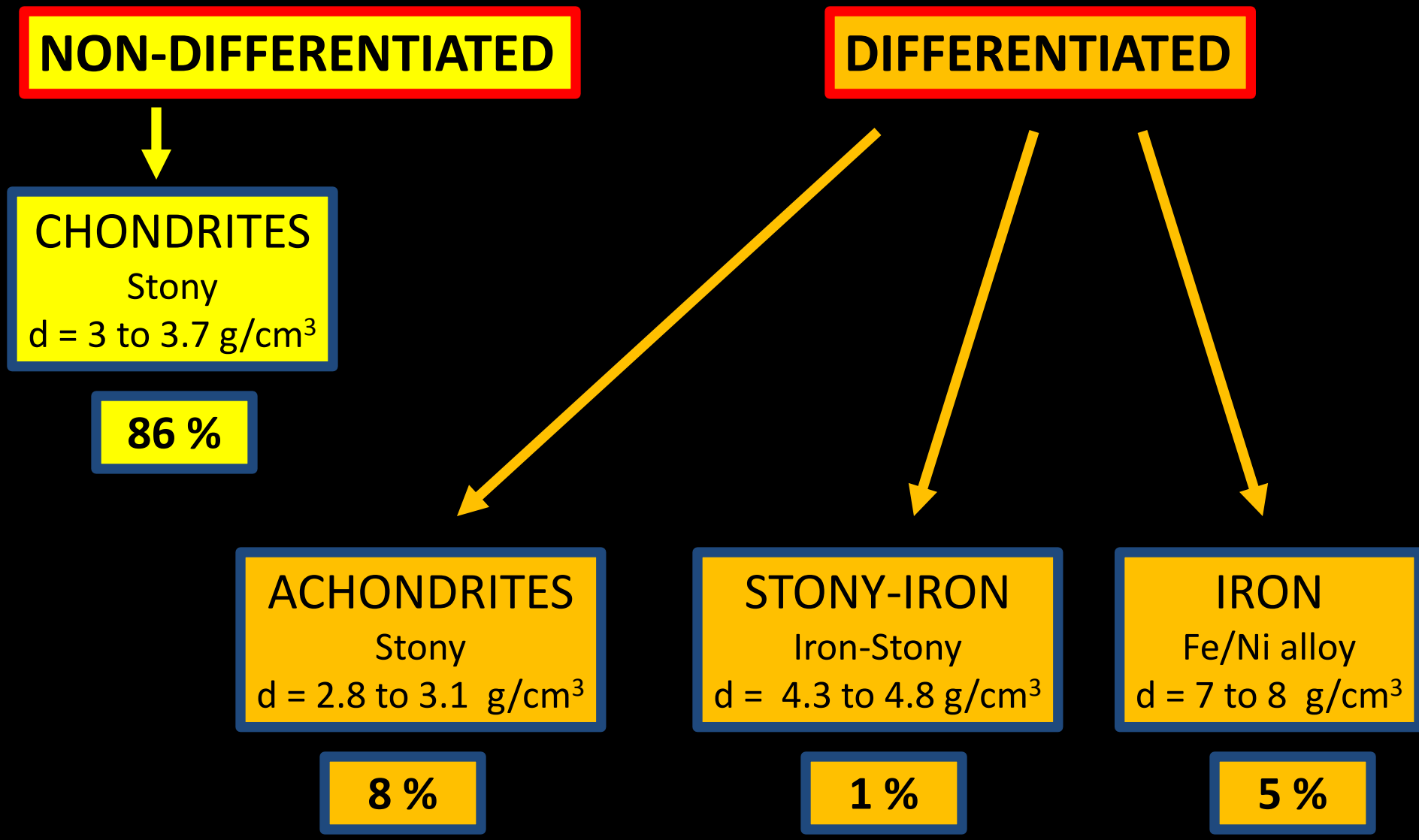
Light emitted by a meteoroid in the atmosphere

A meteor brighter than Venus

Light emitted by a large meteoroid as it explodes In the atmosphere

A fragment of a meteoroid that survives passage through the atmosphere and hits the ground

CLASSIFICATION OF METEORITES

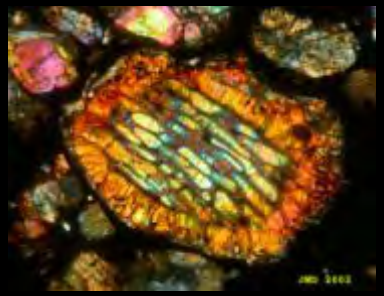


NON-DIFFERENTIATED METEORITES : CHONDRITES

- ORDINARY
  - H
  - L
  - LL
- CARBONACEOUS
  - CB
  - CH
  - CK
  - CM
  - CR
  - CV
  - CO
  - CI
- ENSTATITE
  - EH
  - EL
- RUMURUTI
- KAKANGARI

NON-DIFFERENTIATED METEORITES : CHONDRITES

Chondrites are stony meteorites, named the presence of small spherical bodies, about 1 mm in diameter named **chondrules.**
From their shapes and the texture of the crystals in them, **chondrule**s appear to have been free-floating molten droplets in the solar nebula.



Olivine Chondrule

Olivine+ Pyroxene Chondrule

They are typically about **4,566.6 ± 1.0 By** old, which is then dating the formation of the Solar System itself.

Chondrites are thought to represent material from the Solar System that never coalesced into large bodies. Chondritic asteroids are some of the oldest and most primitive materials in the solar system.

Other Components :

- Refractory inclusions (including Ca-Al)
- Particles rich in metallic Fe-Ni and sulfides
- Isolated grains of silicate minerals
- A matrix of fine-grained (µm or less) dust
- Presolar grains

ORDINARY CHONDRITES : 87%

Ordinary Chondrites are thought to have originated from three parent asteroids within the Asteroid Belt, between Mars and Jupiter : 6 Hebe, 243 Ida and 3628 Boznemcova.

H — **H**ighest total iron, high metal, but lower iron oxide

L — **L**ower total iron, lower metal, but higher iron oxide

LL — **L**ow total iron and **L**ow metal, but the highest iron oxide

CARBONACEOUS CHONDRITES

Groups of carbonaceous chondrites contain high percentages (3% to 22%) of water and organic compounds. Composed mainly of silicates, oxides and sulfides,.
The presence of volatile organic chemicals and water indicates that they have not undergone significant heating (>200°C) since they were formed, and their compositions are considered to be close to that of the solar nebula from which the Solar System condensed

CH High Metal : Pyroxene, metals, Olivine

CB Bencubbin : Pyroxene, metals

CK Karrunda : Olivine, Ca minerals and Al

CM Mighei : Phylosilicates, Olivine

CR Renazzo : Phylosilicates, Olivine, Pyroxene, metal

CV Viragano : Olivine rich in Fe, Ca minerals and Al

CO Ornans : Olivine, Pyroxene, metals, Ca minerals and Al

CI Ivuna : Phylosilicates, Magnetite

ENSTATITE CHONDRITES

(Enstatite is a magnesium-rich Pyroxene)

EH High Enstatite

EL Low Enstatite

Dominantly composed of Enstatite-rich chondrules plus abundant grains of metal and sulfide minerals

Their lack of oxygen content may mean that they were originally formed near the centre of the solar nebula that created the solar system, possibly within the orbit of Mercury

From 21 Lutecia?

DIFFERENTIATED METEORITES

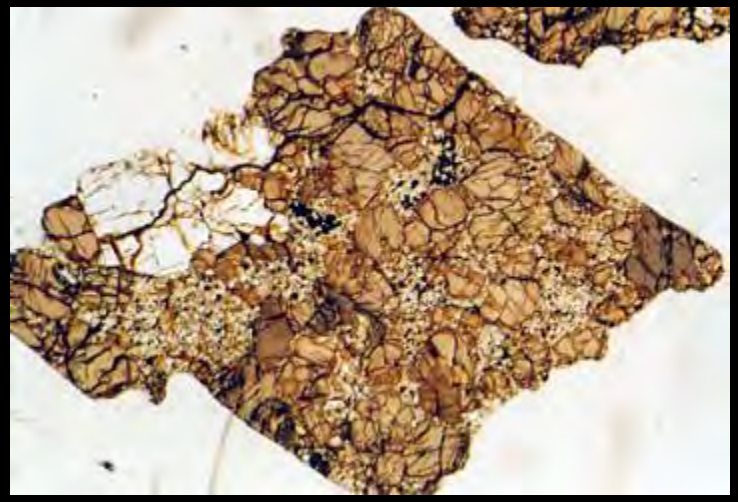
- ACHONDRITES
  - PRIMITIVE
  - ASTEROIDAL
  - LUNAR
  - MARTIAN
- STONY-IRON
  - PALLASITES
  - MESOSIDERITES
- IRON
  - I AB
  - II AB
  - III AB
  - IV AB
  - Ungr.
  - Other

DIFFERENTIATED METEORITES come from celestial bodies which were once melted and differentiated during their formation, as Planetisimals, Protoplanets or even Planets. Consequently, they are younger than non differentiated meteorites

ACHONDRITES are stony meteorites that do not contain chondrules. It consists of material similar to terrestrial basalts or plutonic rocks and has been differentiated and reprocessed to a lesser or greater degree due to melting and recrystallization on or within celestial parent body.

PRIMITIVE ACHONDRITES :
Chemical composition is *primitive* (same than Chondrites) but their texture is igneous, indicative of melting processes. Rare Chondrule relics.

Several groups...



Ungrouped Achondrite : Plane-light photo of olivine phenocrysts surrounded by recrystallized plagioclase, pyroxene, and some olivine. Large white grain is relict plagioclase. Base width = 5 mm.

Group : Lodranite

Group : Vinoaite

Group : Ureilite

ASTEROIDAL ACHONDRITES (or : Evolved Achondites)

They have been differentiated on a parent body. This means that their mineralogical and chemical composition was changed by melting and crytallization processes.

HED, all from 4 Vesta

Howardite =Regolith breccia made of Eucrite and Diogenite

Eucrite = Basaltic rock

Diogenite = Plutonic rock, Olivine+OPX+ Plagioclase

LUNAR ACHONDRITES

Basalts, Basaltic or Gabbroic Breccias, Gabbros etc...

MARTIAN ACHONDRITES

Orthopyrexonite, Dunite, Lherzolite etc...

STONY-IRON METEORITES

Stony-iron meteorites are meteorites that consist of nearly equal parts of meteoric iron and silicates.

PALLASITES

They consists of centimetre-sized olivine crystals in an iron-nickel matrix.

MESOSIDERITES

Breccias with an irregular texture; The silicate part contains olivine pyroxenes and Ca-rich feldspar and is similar in composition to eucrites and diogenites.

IRON METEORITES

THEY ARE ORIGINATED FROM THE CORE of the PARENT BODY WHICH HAVE of course, BEEN DIFFERENTIATED , mainly in the ASTEROID BELT. ABOUT 50 PARENT BODIES HAVE BEEN RECOGNIZED TO NOW.

Regmaglypts or “Thumbprints”, a feature unique to meteorites, due to outer layer melting

They are made of iron–nickel alloy , known as meteoric iron .

- I AB
- II AB
- III AB
- IV AB
- Ungr.
- Other

Chemical classification is based on the proportions of Nickel against Ga , Ge and Ir

When cut, polished, and treated with acid, the surface of Iron Meteorites shows "Widmanstätten structure“. It consists of a fine interleaving of kamacite and taenite (2 different Fe -Ni alloys) bands.

The HOBA meteorite is the largest Iron meteorite ever found on Earth, in northern Namibia. It weight 60 tonnes.

Meteorites of Zimbabwe....

NAME	PLACE	(1) Fall or (2)Found	TYPE	Seize	Weight
MANGWENDI *(Approved)*	Mash. East	(1) 7th March 1934	**CHONDRITE LL 6**	24x22x18 cm	22.3 kg
MAFUTA *(Approved)*	Makonde D Mash. East	(2) 1st Nov 1984	**IRON II D**	40x20 cm	71.5 kg
MAGOMBEDZE *(Approved)*	Mashvingo	(1) 2nd July 1990	**CHONDRITE H 35**		0.666 kg
DITOTO *(Not Approved)*	Kadenya Mt Darwin	(1) 22nd Aug. 2005	**CHONDRITE?**	30 cm	6 kg
NKAYI *(Approved)*	Nkayi D Mata. North	(1) 1st March 2009	**CHONDRITE L 6**		100 kg

Approved or Not Approved by : The **Meteoritical Society,** an organization that records all known meteorites in its *Meteoritical Bulletin*


FALL/ FINDING LOCATIONS
Lake Cahora Bassa
Tete
Mafuta
Ditoto
Southern
Lake Kariba
Mongwandi
Harare
Inyanga Mountain
35
Nkayi
Zimbabwe
36
Magombedze
Bulawayo
K
Central

MANGWENDI METEORITE
Chondrite LL 6, 22.3 kg, 1934)

MAFUTA METEORITE , Iron II D, 71.5 kg, 1984

MAGOMBEDZE METEORITE
Chondrite H 35, 0.666 kg, 1990

Fig. 2. Photograph of the main Magombedze stone where it land
a field near Mr. Charidza (shown).

Fig. 4. Closeup of the interior of Magombedze showing light a
rk fragments within a somewhat darker matrix.

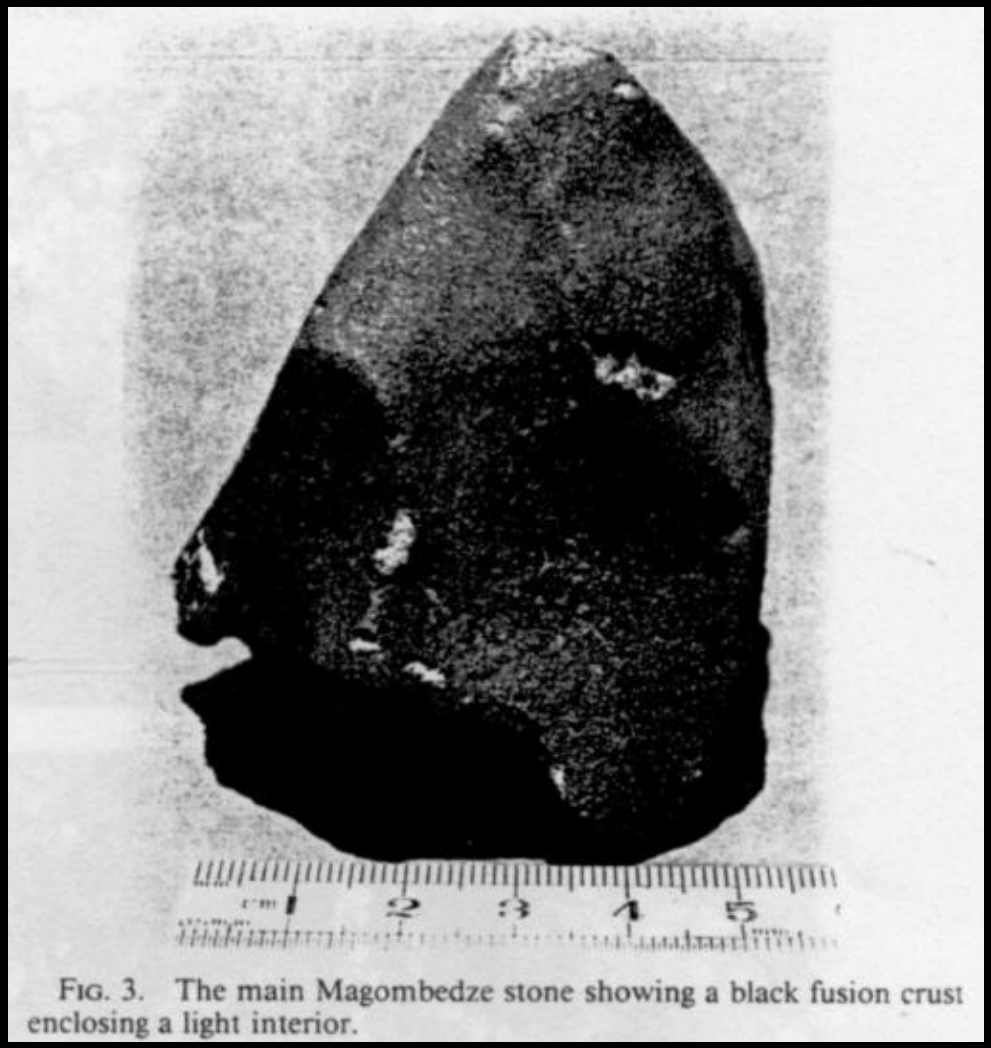
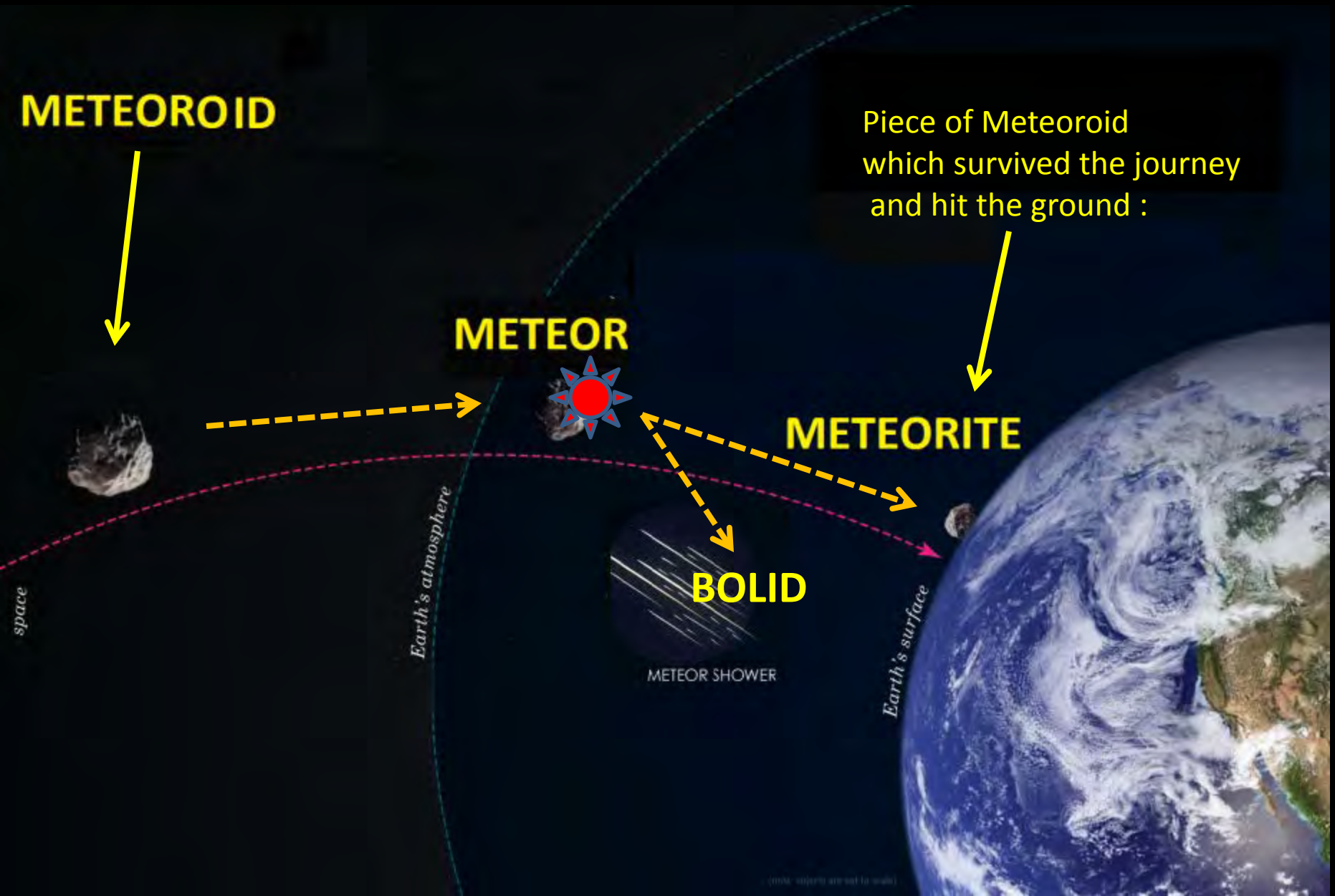


Fig. 3. The main Magombedze stone showing a black fusion crust enclosing a light interior.

DITOTO METEORITE
Chondrite?, 6 kg, 2005

NKAYI METEORITE
Chondrite L 6, 100 kg, 2009

WHAT IS HAPPENING WHEN A METEOROID ENTERS THE EARTH ATMOSPHERE?



WHAT IS HAPPENING WHEN A METEOROID ENTERS THE EARTH ATMOSPHERE?

- Depending on **size, type** (d), **speed** and **incoming angle**, Meteoroids entering the earth's atmosphere will undergo friction (heat and partial melting) , pressure (cracks and fragmentation) and chemical interactions with the atmosphere gases (colour, brightness).

They also slow down, but almost not for the biggest ones, especially of Iron-type.

Tiny Particles

- Every year, 15 to 50 thousand tonnes of extraterrestrial material fall from Space on Planet Earth.
- 95% consists of tiny particles weighting less than 0.01 g.
- When not burnt, they can be very quickly slowed by the pressure of the atmosphere and finish their journey gliding to the ground.
- They are then mixed to the soil and sea sediments.

Small Particles

- Small particles (around 1 to few mm in diameter) entering in the Earth atmosphere are quickly entirely burnt by the friction with the air.

- They are what we call usually “falling stars”, or when they are numerous, like when Earth is crossing the old path of a comet , It’s the “ Meteor Showers”.
- They become visible at around 100 km up.

Medium sized-meteoroids

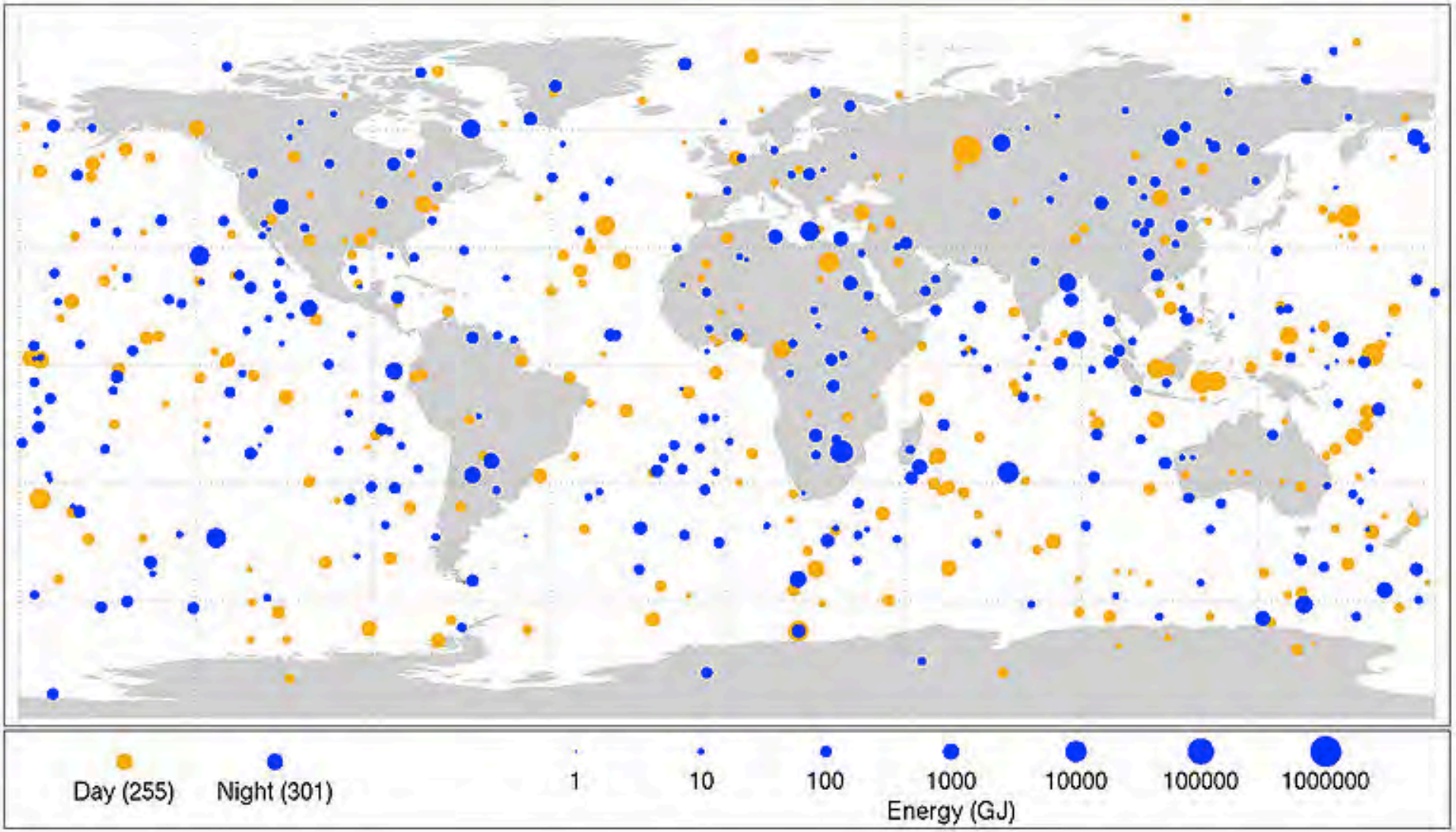
Over UK

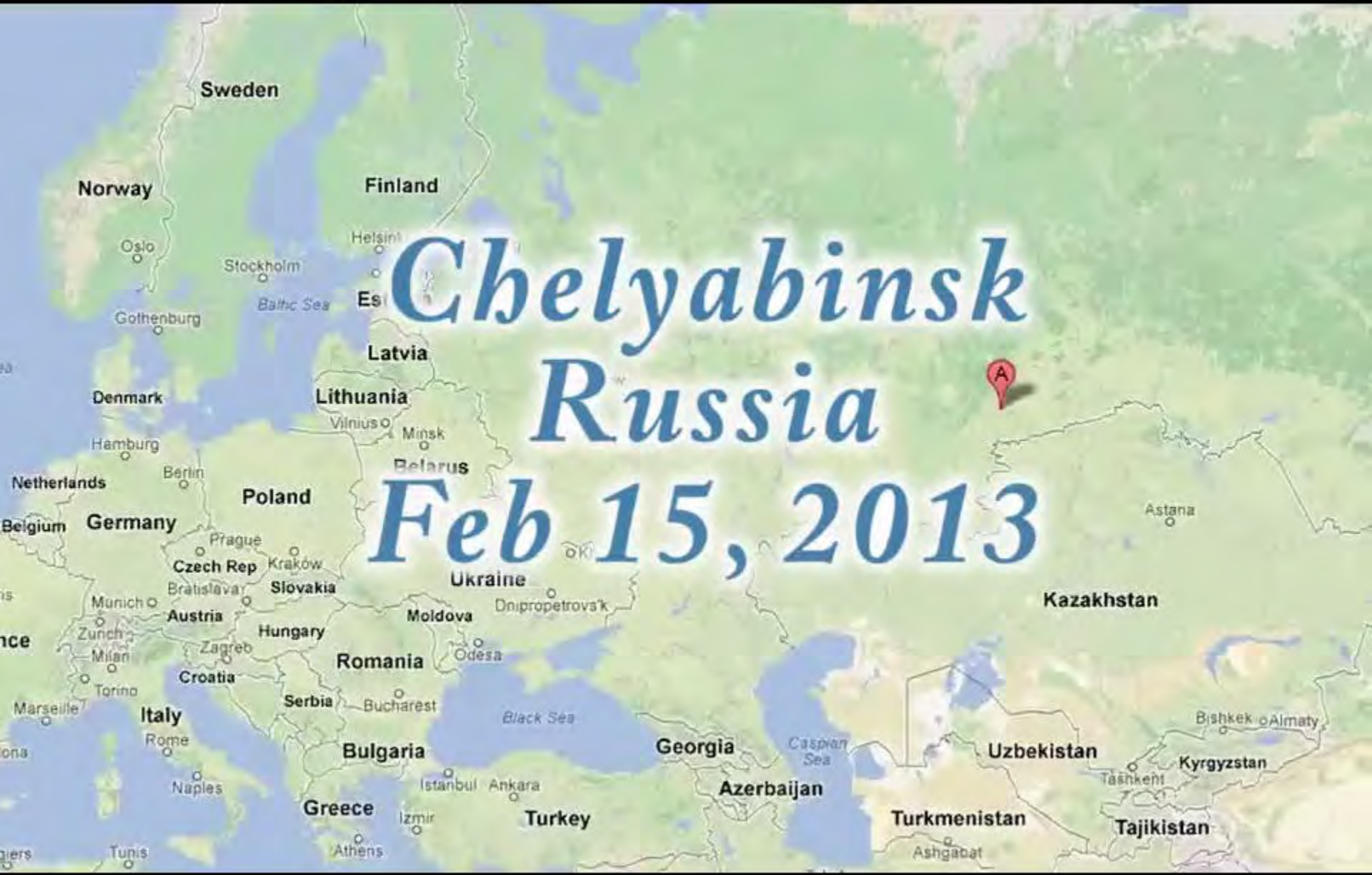
Chelyabinsk, Russia

- The majority of them is burning or melting during the journey through the atmosphere , forming Meteors or Fireballs.
- When they explode they are named Bolides.
- Small Fragments can reach the ground, but they did not create impact craters (i.e the MAGOMBEDZE or the MANGWENDI meteorites of Zimbabwe).
- Sounds can be heard over wide areas : Explosions, detonations and rumblings

Bolide events 1994-2013

(Small asteroids that disintegrated in the Earth's atmosphere)




Chelyabinsk
Russia
Feb 15, 2013
Sweden
Norway
Finland
Oslo
Stockholm
Helsinki
Baltic Sea
Gothenburg
Latvia
Denmark
Lithuania
Vilnius
Minsk
Belarus
Hamburg
Berlin
Netherlands
Poland
Belgium
Germany
Prague
Czech Rep
Kraków
Bratislava
Slovakia
Ukraine
Dnipropetrovs'k
Munich
Austria
Moldova
Kazakhstan
Zurich
Hungary
Milan
Zagreb
Odesa
Romania
Croatia
Torino
Marseille
Serbia
Bucharest
Italy
Black Sea
Rome
Bishkek
Almaty
Bulgaria
Georgia
Caspian Sea
Uzbekistan
Kyrgyzstan
Naples
Istanbul
Ankara
Tashkent
Azerbaijan
Greece
Izmir
Turkey
Turkmenistan
Tajikistan
Tunis
Athens
Ashgabat
Astana

The TUNGUSTA EVENT

30th of June, 1908

The explosion was attributed to the mid-air disruption of a superbolide of more than 60 m in diameter. No impact crater has been found; the object is thought to have disintegrated at an altitude of 5 to 10 kilometres rather than hit the surface of the Earth.

It is estimated that the Tunguska explosion knocked down some 80 million trees over an area of 2,150 square kilometres .

The superbolide's size, is on the order of 60 to 190 metres, depending on what it was .

Big Asteroids, Very Big Asteroids...

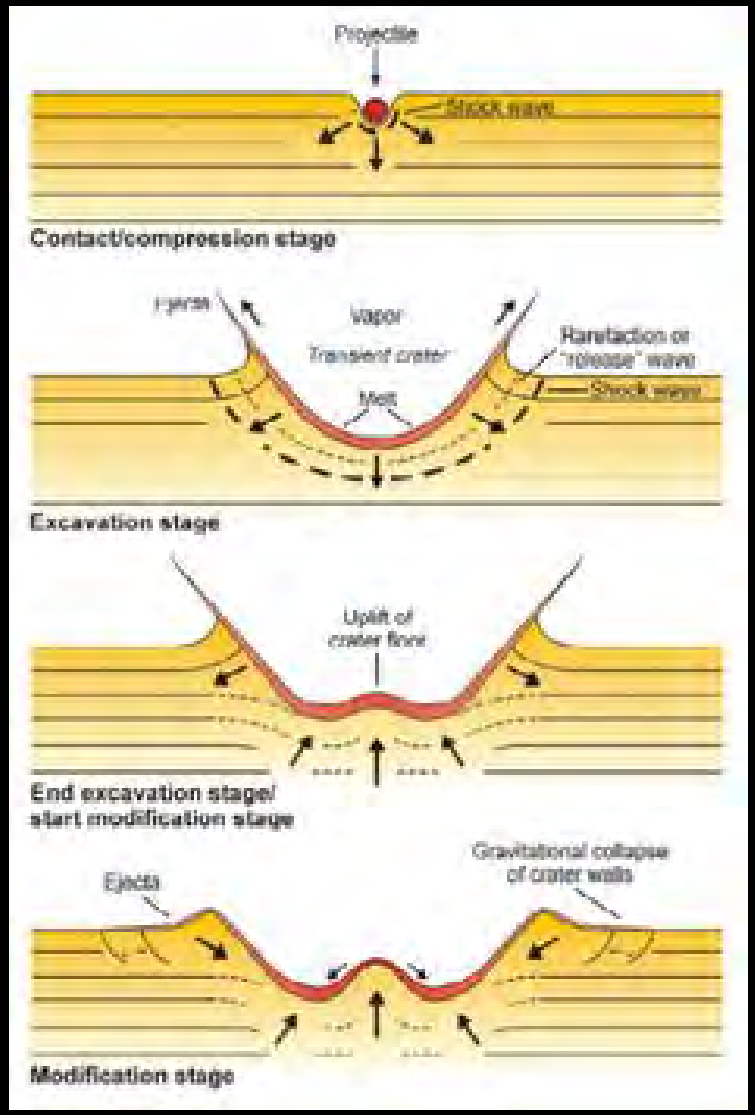
- Big asteroids.... Big problem...
- They can speed through the atmosphere at about 50,000 km/h (14 km/s) and reach a surface temperatures of about 1,650 ^{o} C).

The probability of Earth being hit by an Asteroid of 10 km in diameter is ONE for 100 M YEARS !

Hit the ground or not?

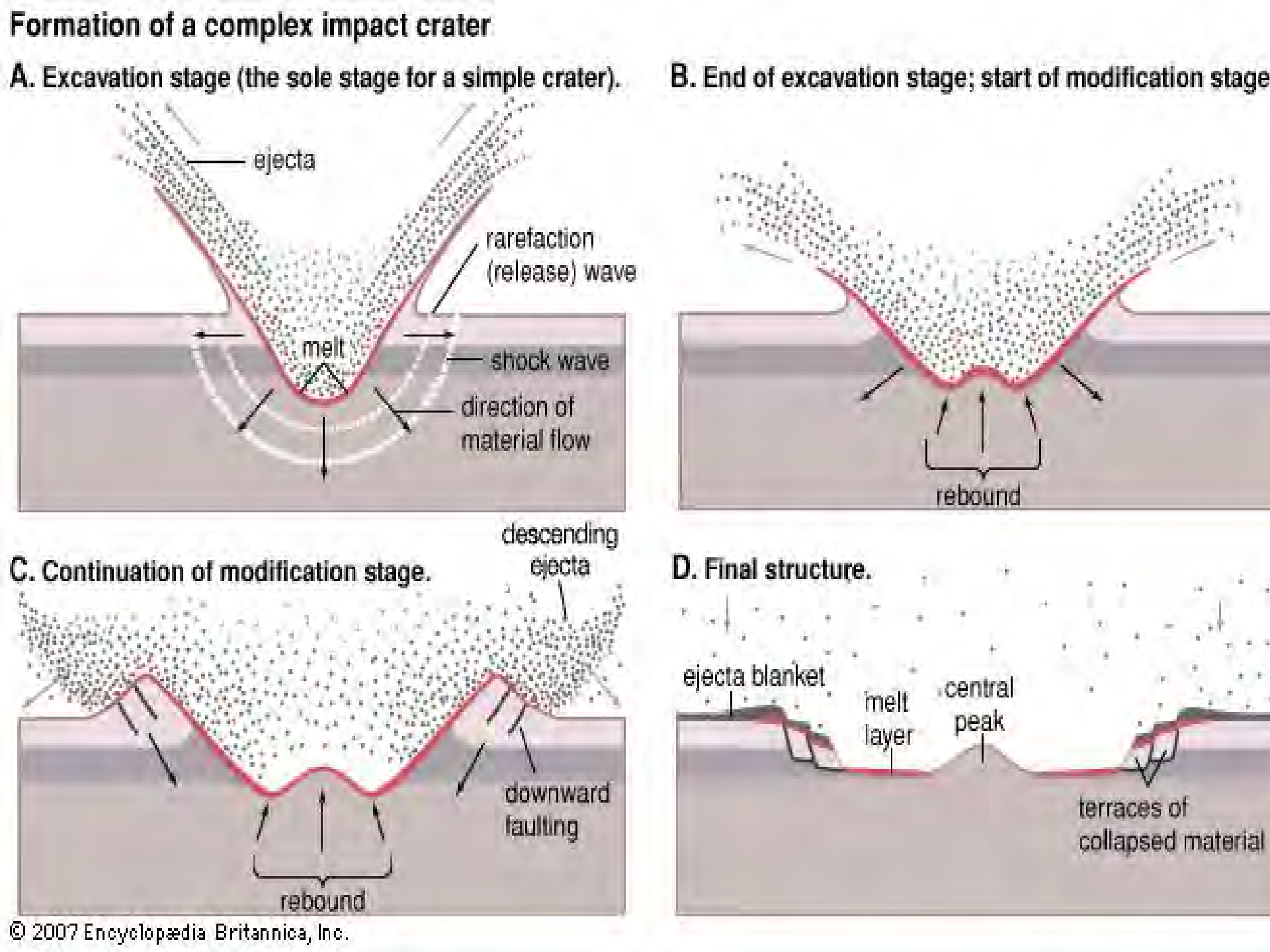
- Meteoroids usually breaks apart in the Earth's atmosphere. A faster meteoroid at an oblique angle suffers greater stress. Stony Meteors or Small Comets up to millions of tonnes are usually disrupted in the atmosphere. Iron Meteors withstand the stress better than stony ones.
- But even an iron meteoroid will usually break up as the atmosphere becomes denser, around 8 to 11 km up. But sometimes when large enough it can reach the ground.

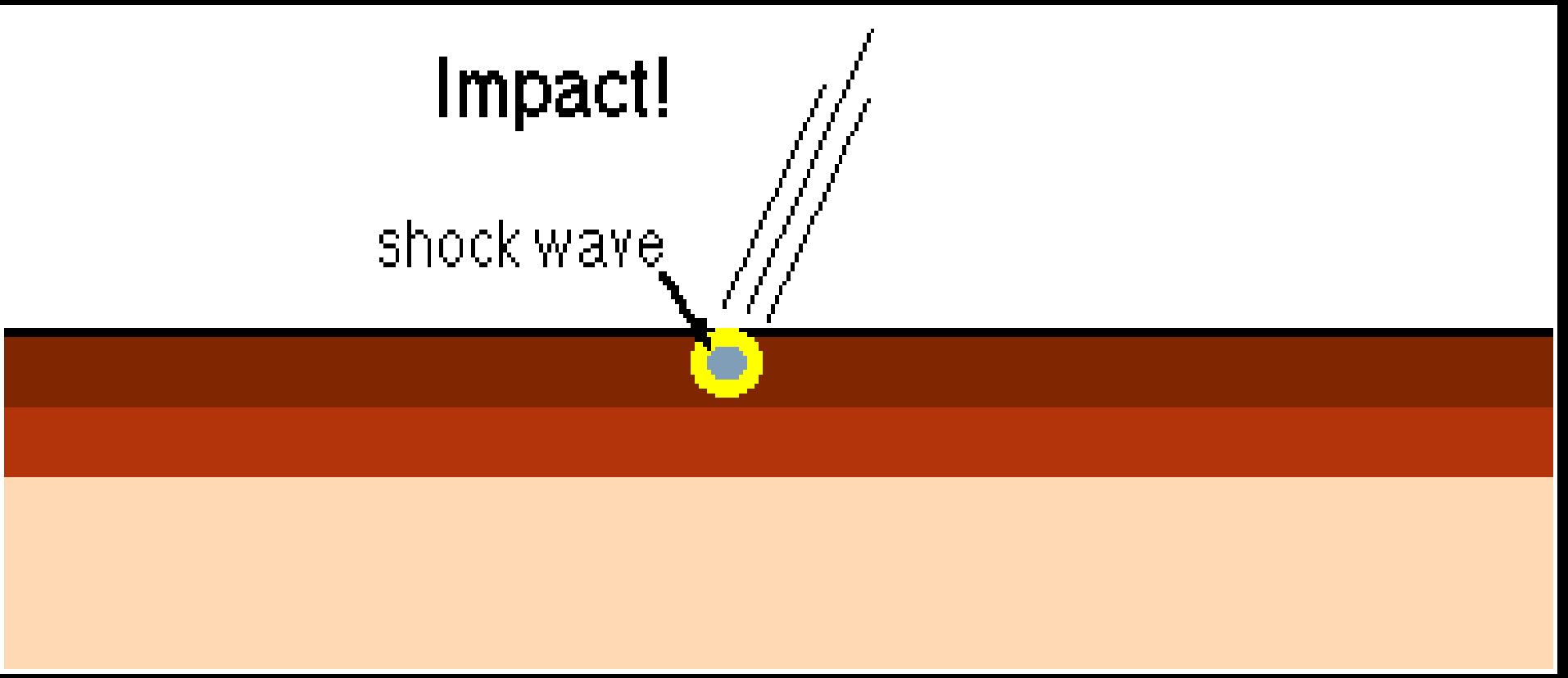
IMPACT !



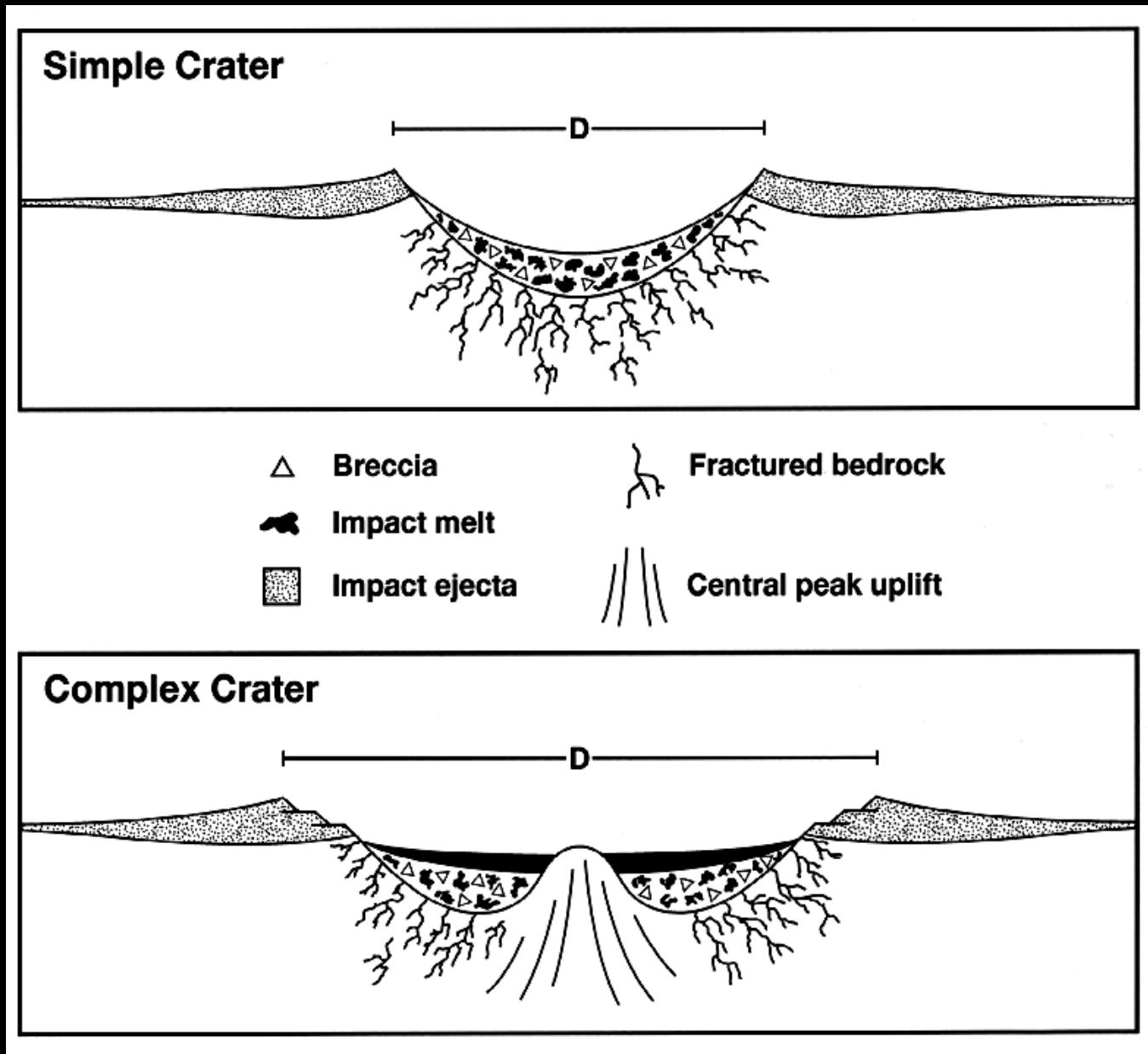
- An impact event is similar to an explosion. That's why all impact craters are circular, never elliptic.
- When an asteroid hit the Earth's surface at a speed of 11 km/s to 30 km/s, only a fraction of the object is vaporized, while most of the object is melted with a fraction staying solid, but completely fractured. Most of the impactor (>99.9%) is ejected in the impact process and little if any stays in the crater.

Experimentation and calculations showed that on average, the impact crater is 20 times the diameter of the impacting Asteroid




Impact!
shock wave

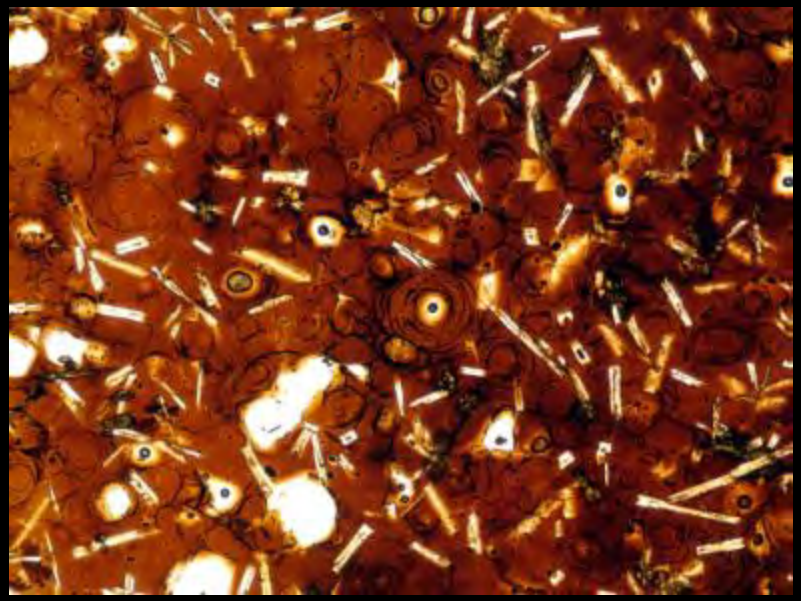
IMPACTITES


Simple Crater
D
Breccia
Impact melt
Impact ejecta
Fractured bedrock
Central peak uplift
Complex Crater
D

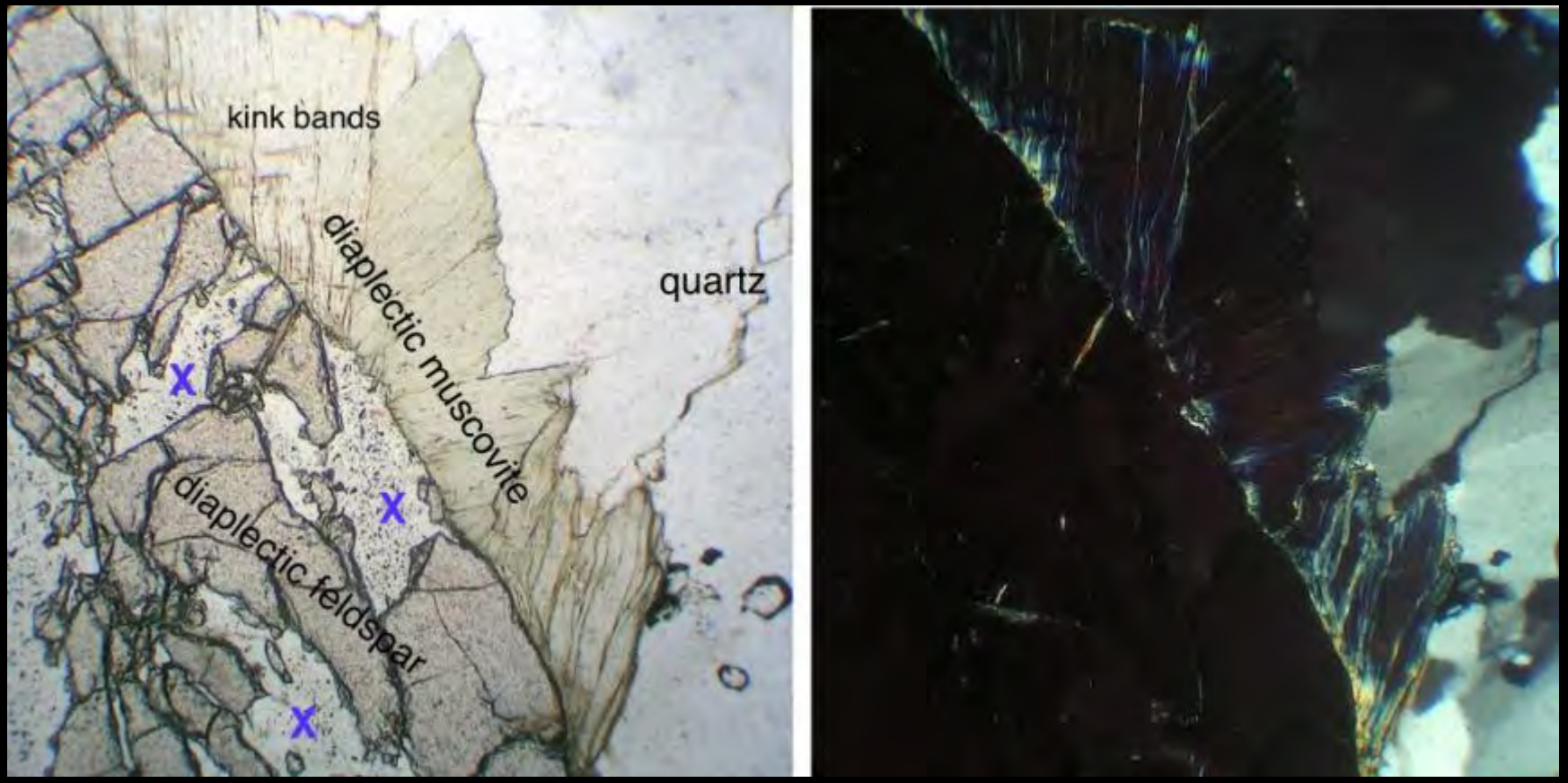
Impact Breccias = Suevite, Tagamite

Suevite is a brecciated rock containing diaplectic glass and crystals or lithic fragments.

Rocks formed from more completely melted material found in the crater floor are known as ***tagamites***



Diaplectic Glass

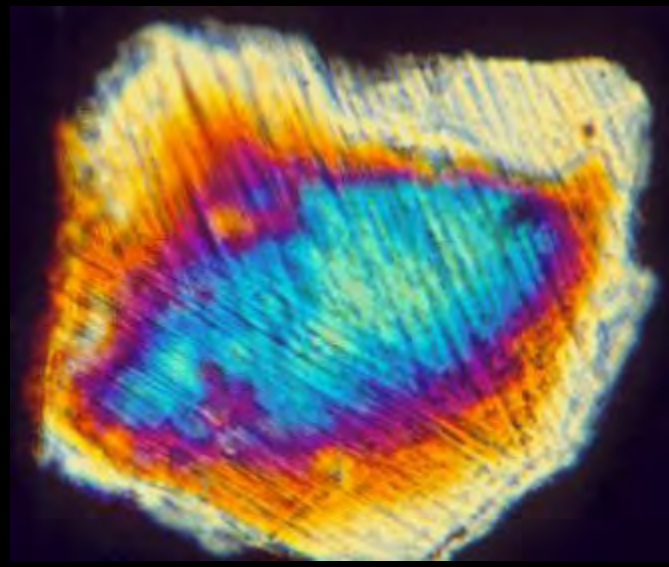


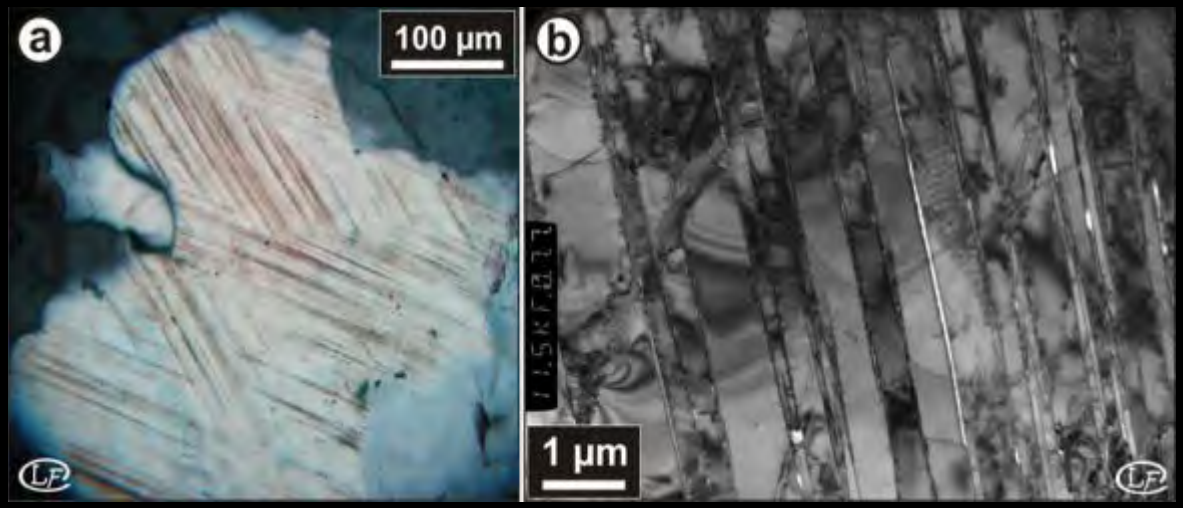
Glass formed through fusion of different minerals – not melted, but sintered…

Sintering is the process of compacting and forming a solid mass of material by heat and/or pressure without melting it to the point of liquefaction

PDF'S (Shock Quartz)

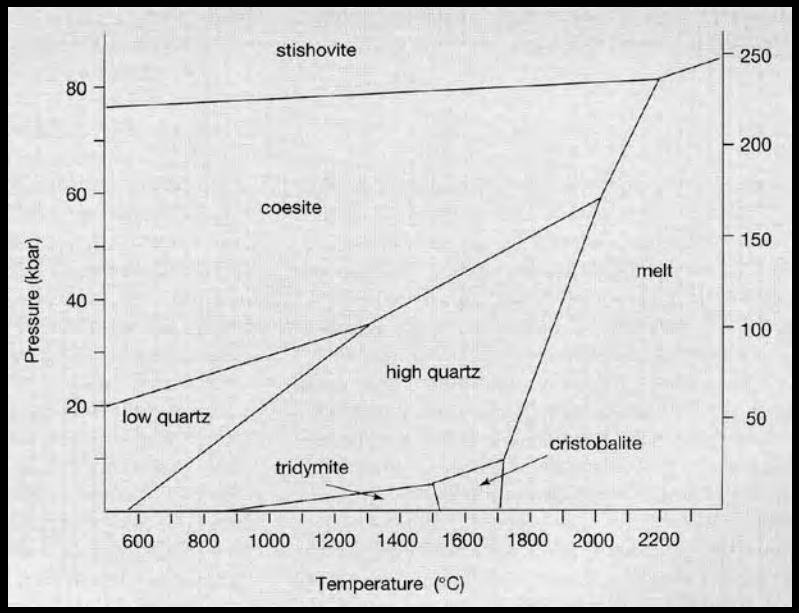
Planar deformation features are optically recognizable microscopic features in grains of quartz or feldspar, consisting of very narrow planes of glassy material arranged in parallel sets that have distinct orientations.

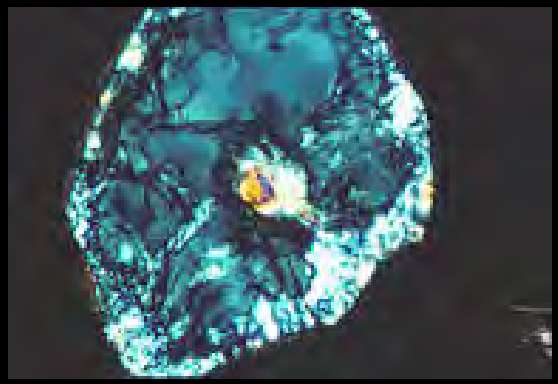




High Pressure Polymorphs

- High Pressure quartz : Coesite and Stishovite





Coesite

Very Small hexagonal Diamonds : Lonsdaleite

But also Reidite, from Zircon..
Majorite, from Pyroxene..
Jadeite, from Plagioclase..
Ringwoodite from Olivine..

Shatter Cones

Conical striated fracture surfaces

Shatter cones occur usually in the central uplifts of complex impact structures.

Shatter cone apex orientation is used to determine the centre of a crater

Ries crater impact ejecta on top of the autochthonous Malmian limestones in the Gundelsheim quarry (about 20 km away from the crater center).

Ejecta Blankets

An **ejecta blanket** is a generally symmetrical apron of ejecta that surrounds an impact crater; it is layered thickly at the crater's rim (proximal ejecta) and thin to discontinuous at the blanket's outer edge (distal ejecta).

Ries crater impact (24 km, Bavaria) ejecta, (about 14 km away from the crater center)

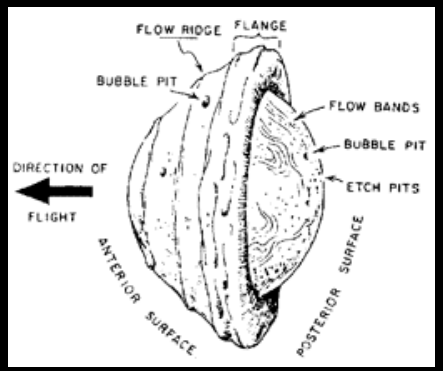
(about 20 km away from the crater center).

Tektites

- Tektites are pieces of Earth rocks that have been melted and thrown into space by a large impact . It was still liquid as it passed back down through Earth's atmosphere, so it became aerodynamically shaped. Cooling was so fast that the mineral solidified as a glass, not as a crystalline material.

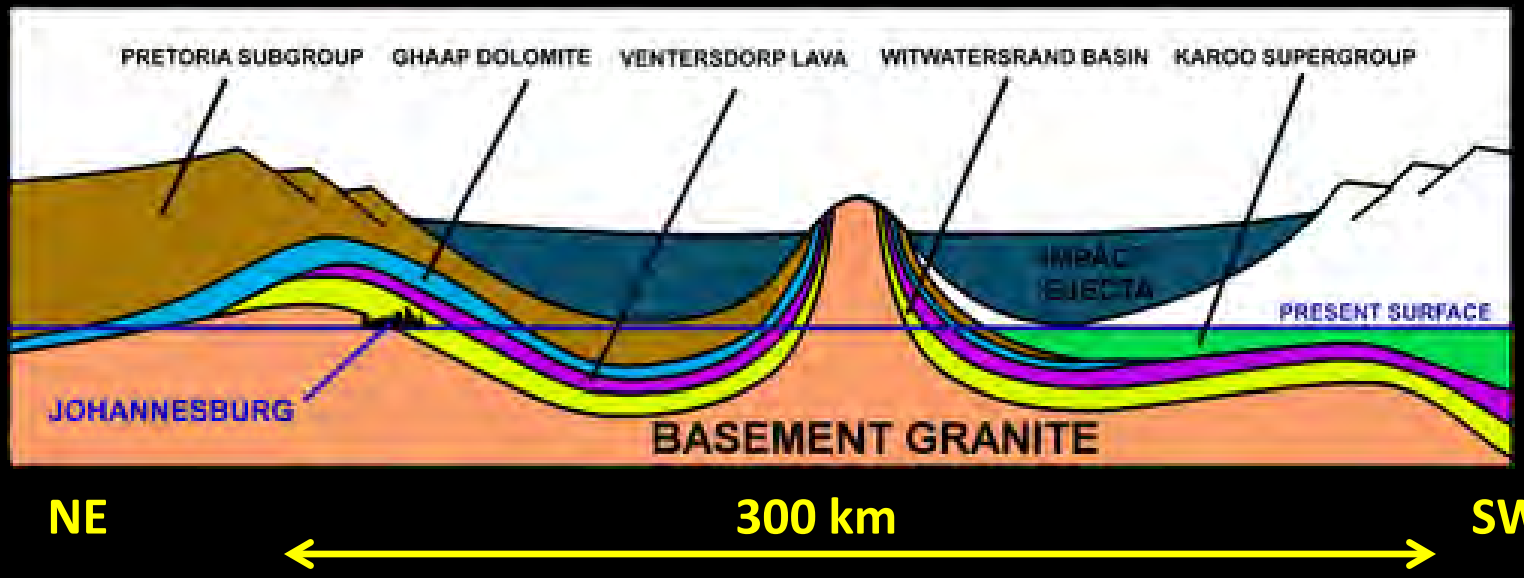
Moldavite

Australite

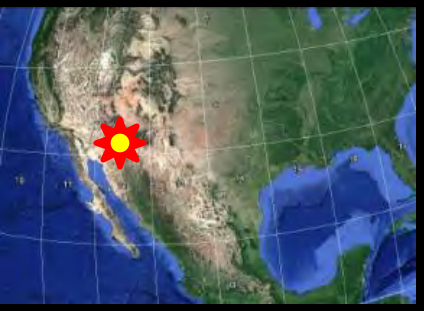


The Vredeford Impact Crater (South Africa) : the largest one...

Age : 2.020 By
Estimated initial Diameter : 300 km
The remaining rebound structure is the Vredeford Dome, 70 km across.
Formed by the impact of a 15 to 20 km Asteroid




Johannesburg
35
Vredefort Dome
100 km
Image Landsat



Meteor (or Barringer) Crater, Arizona :

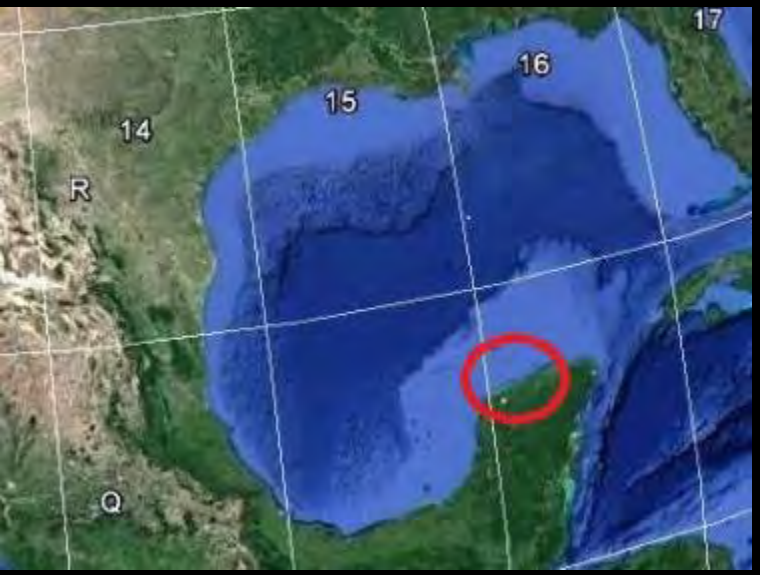
The most famous, most studied, most visited...

Diameter : 1250m
Depth : 175 m
Iron Asteroid, 40 m wide hit the ground at 15 km/s
Age : 50,000 years.

Numerous Iron meteorites, weighting 1 to 500 kg were found in a 10 km diameter circle around the crater.

The Chicxulub Meteor Crater (Yucatan, Mexico).

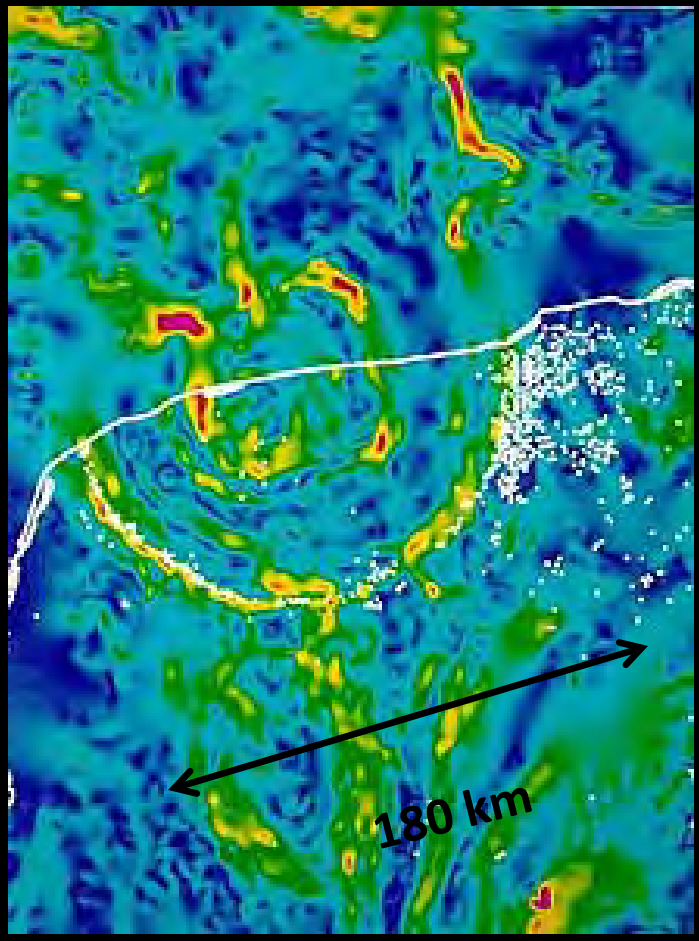
The most disastrous, to the point of view of Dinosaurs and some other species...



Age : 66 My Diameter : 180 km

Depth : 20 km

It's a buried crater which was found by Geophysics. Evidence for the impact origin of the crater includes shocked quartz, a gravity anomaly and Tektites in surrounding areas, as far as Hispaniola Island (Haiti + Santo Domingo)



Gravity anomaly map of the Yukatan

Other Impact Craters....

Gosses Bluff, Australia, 5 km

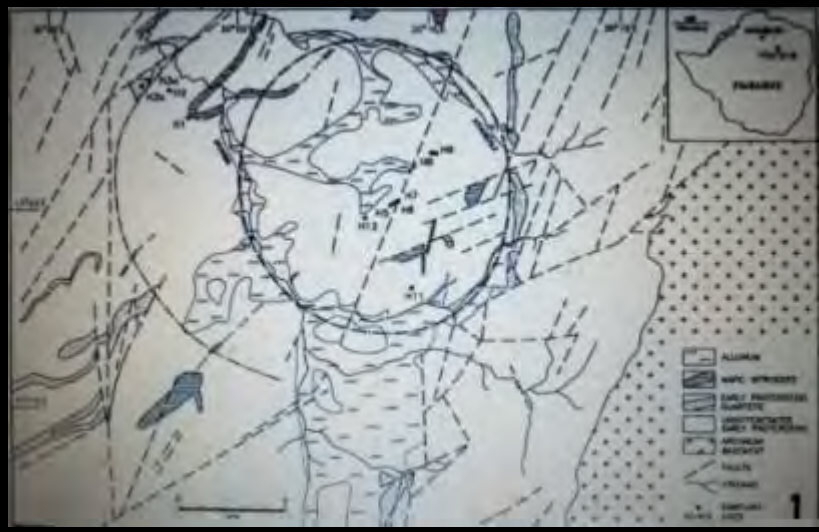
Amguid Crater, Algeria, 500 m

Aorounga Crater, Chad, 17 km
(Radar Image)

Ouarkziz Crater, Algeria, 3.5 km

IMPACT CRATERS of ZIMBABWE

Highbury Impact Crater

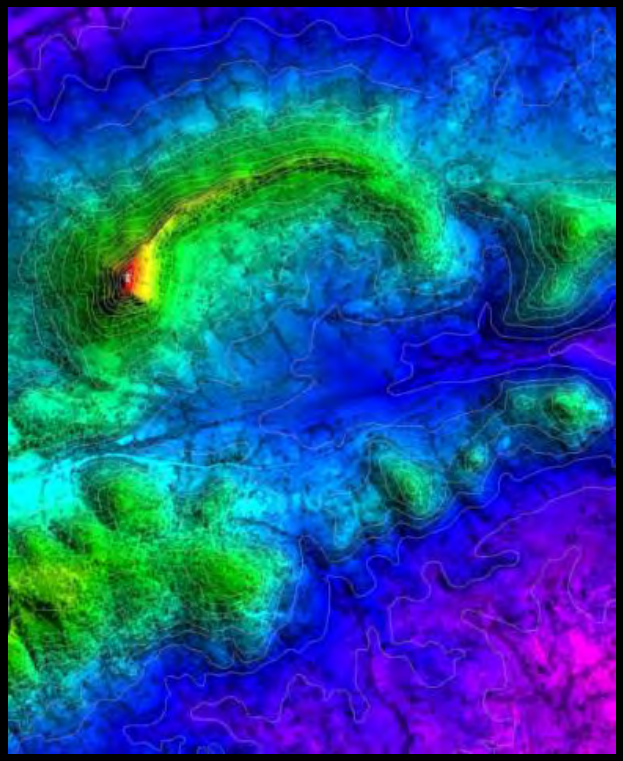


- 15 to 25 km in diameter...
- Impact on arkoses and metadolerites
of the Deweras Group Early Proterozoic).
About the center of the impact crater, outcrops of
Geothite-rich breccias show PDF's in quartz cristals.

(Master S. et *al,* 1994)

Furume Impact Crater

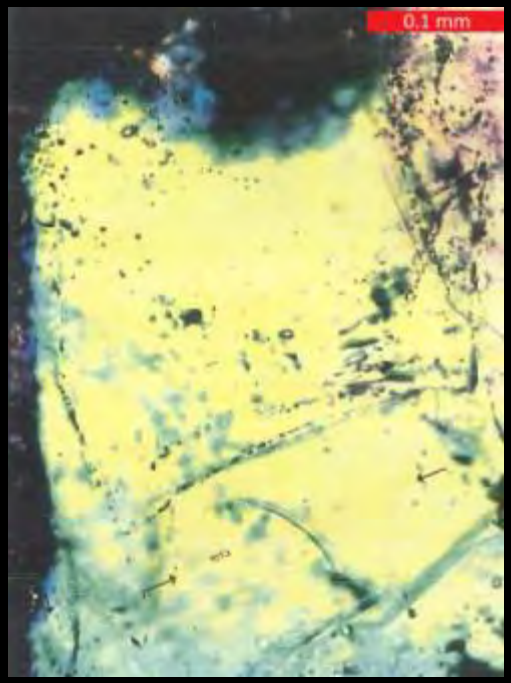
DTM



Ndanga C L, west of Mashvingo
2 km in diameter...Radial fractures.....Brecciation by places...No traces of ejecta...
Could be the structure at depth of an old impact structure

(Tim Broderick, Andrew du Toit, Adolph Chikasha, 2008)

Sinamwenda Impact Crater



PDF's in Quartz

(Master S. , 2015)

Thank you.....