BASICS OF IMPACT CRATERING & GEOLOGICAL, GEOPHYSICAL, GEOCHEMICAL, ENVIRONMENTAL STUDIES OF SOME IMPACT CRATERS OF THE EARTH

IAP 2008 12.091 Special Topics Course
January 8 – 22, 2008

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SESSION 1: January 8, 2008

COURSE OUTLINE

1. Introduction to Terrestrial Impact Cratering
2. Review of Some Major Research Studies of Terrestrial Impact Craters
3. Tools of Analysis
4. Impact Crater: Chesapeake Bay Well Logging and Geochemical Studies
5. Impact Cratering: Economic Potential and Environmental Effects
6. Conclusion

On completion of this course

You will gain knowledge of

- Criteria for identification of terrestrial impact craters
- Evaluation of parameters such as size, impactor velocity, ...
- Research studies of age determination and correlation with events such as mass extinction,
- Economics of geological ore formation
- Effects of ejected deposits on the surrounding environment that creates an interest to pursue a career in medical geology.

DETAILED COURSE WORK

The course work involves the following:

- January 8, 10, 15, 17, 22 10 AM to Noon
- 5 sessions each of 2 hours - 25%
- Study/work assignments – 4 - 20%
- Project

  Literature Survey &

  Writing a report - 30%
- Project Presentation - 25%
- Required percentage to pass this course is 95%
- Grading: P/F

Session 1

Introduction to Terrestrial Impact Cratering

SESSION 1 OBJECTIVES

1. Introduction
2. Review of Terminology
3. Historic Understanding of Impact Craters
4. Need to Study Impact Craters
5. Terrestrial Impact Crater Identification Criteria
6. Some Impact Craters of the World
7. Understanding Impact Event – Summary

INTRODUCTION

Terrestrial Impact Cratering

Impact

unique

short-time

high-energy

high-temperature

geological

process.

INTRODUCTION …

Current findings of impact structures on the Earth surface

about 170

C. KOEBERL Mineralogical Magazine, October 2002, Vol. 66(5), pp. 745–768.

Impact Craters have various

forms,

sizes from <100 m to 300Km

in diameter

ages from recent to 2 billion

years in age

INTRODUCTION …

Impact Event

Impactor Target

How many ways this can happen

SOLID LIQUID GAS

Solid to Solid
Solid to Liquid
Liquid to Liquid
Solid to Gas
Gas to Solid

Simple Case: Solid to Solid

REVIEW OF TERMINOLOGY

Asteroid

irregularly shaped object travelling in orbit, formed by iron-rich silicates or carbon-containing materials or metals like iron and nickel

Comet

mixture of ice, rock and organic material; ice vaporizes in sunlight developing dust and gas and a tail of dust and/or gas.

Meteoroid

interplanetary dust, rock, or debris still in space part of a comet or an asteroid

Review of Terminology ...

Meteor

A meteor

interplanetary

dust, rock, or debris

travelling through the atmosphere

A meteor gets heated to incandescent glow

Meteors are also known as shooting stars.

Meteorite

A meteorite

is a meteor

that has reached the Earth's (planet's)

surface.

Most meteors burn up and never reach the Earth's (planet's) surface.

Asteroid 243 Ida
August 28, 1993

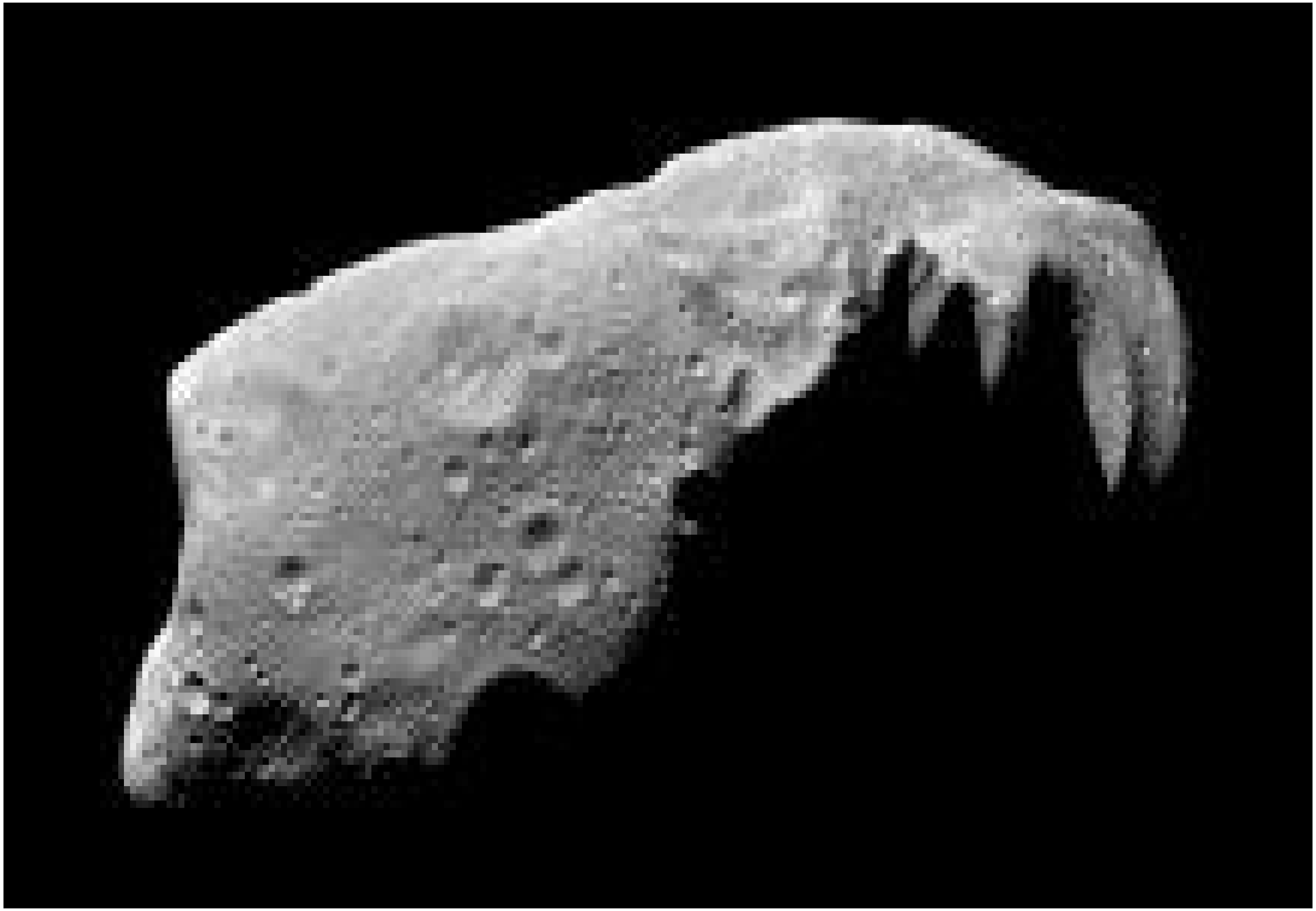


Photo image courtesy of NASA/JPL
http://neo.jpl/nasa/gov/images/ida1.html

Meteors

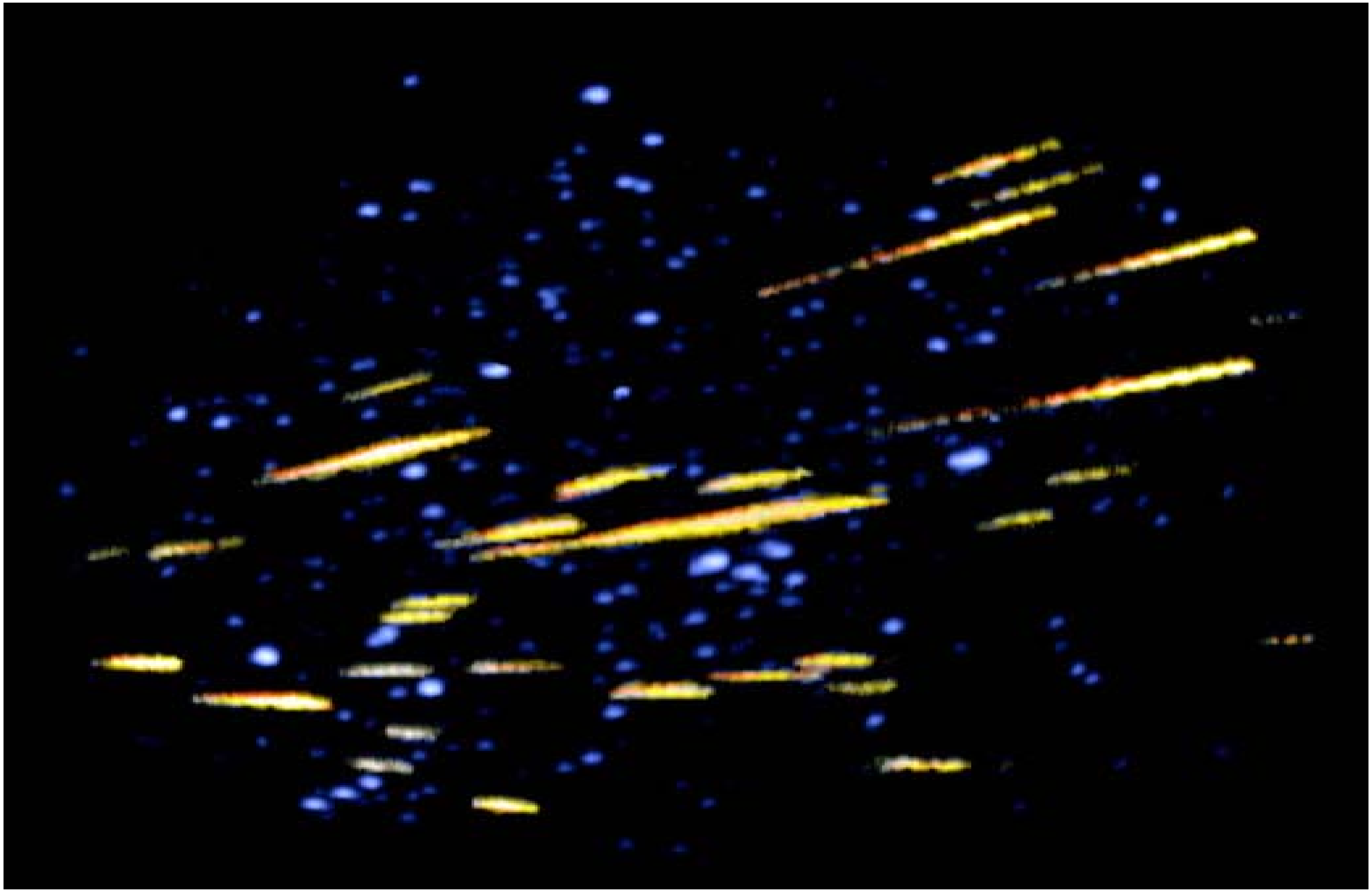


Photo image courtesy of NASA/JPL

LG-2005-12-571-HQ – JPL 400-1253J 12/05

http://www.nasa.gov

Iron Meteorite

primarily of iron and nickel

Photo image courtesy of NASA/JPL
LG-2005-12-571-HQ — JPL 400-1253J 12/05

Stony Iron Meteorite
mixtures of iron and stony material

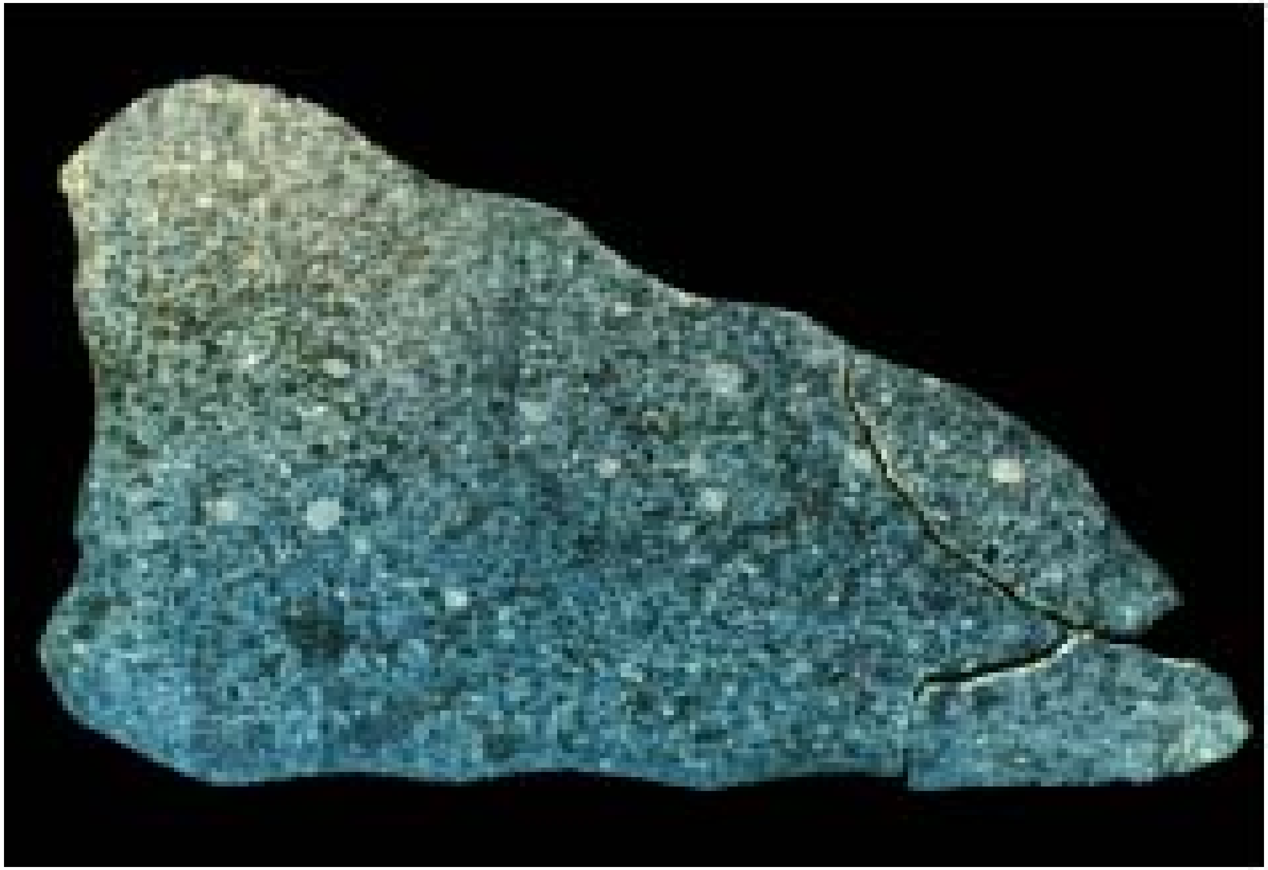


Photo image courtesy of NASA/JPL
LG-2005-12-571-HQ – JPL 400-1253J 12/05

Review of Terminology …
Types of meteorites …

Chondrite:

many meteorites come under this category,
composition is mostly similar to the
mantles and crusts of the terrestrial planets.

Carbonaceous Chondrite:

composition very similar to the Sun,
presence of less volatiles,
similar to type C asteroids.

Achondrite:

do not contain chondrules,
composition similar to terrestrial basalts,
assumed to have origins from the
Moon and Mars.

Review of Terminology …

Types of meteorites …

Chondrites …

- usually stony meteorites with
  surface nodules also called chondrules
- consist of spherical aggregates of
  olivine and /or pyroxene.
- C, E, H, L and LL chondrite**s**

carbonaceous	C chondrites
enstatite	E chondrites
olivine and bronzite	H chondrites
olivine and hypersthene	L and LL chondrites

- H, L and LL are often called ordinary chondrite**s**

Chondrite

- This is a chondritic type meteorite from Antarctica.
- It is considered to have formed at the same time as the planets in the solar nebula, about 4.55 billion years ago.

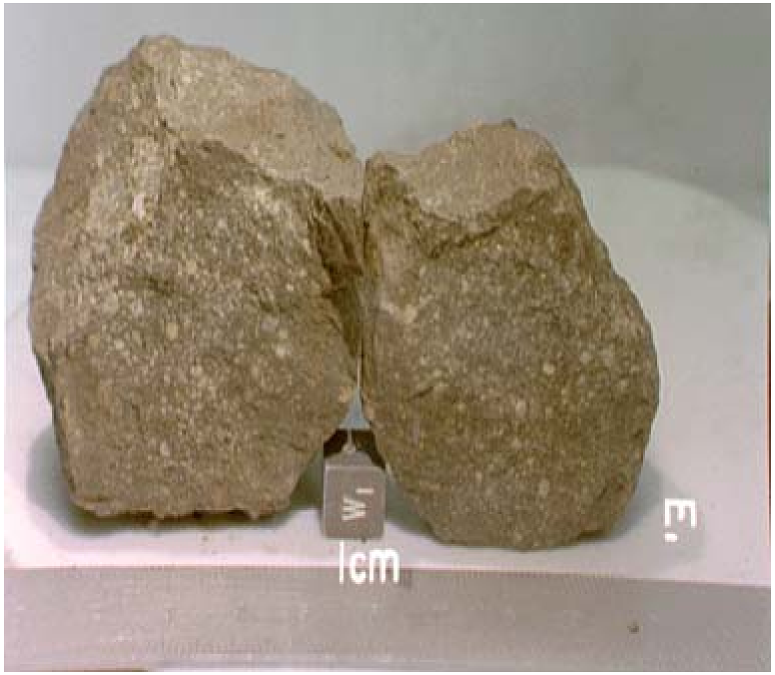


Photo image courtesy of NASA/JPL

Carbonaceous Chondrite Meteorites

Photo image courtesy of NASA/John Space Flight Center
http://science.msfc.nasa.gov/headlines/images/yukon/cc_collection.jpg

Achondrite Meteorite

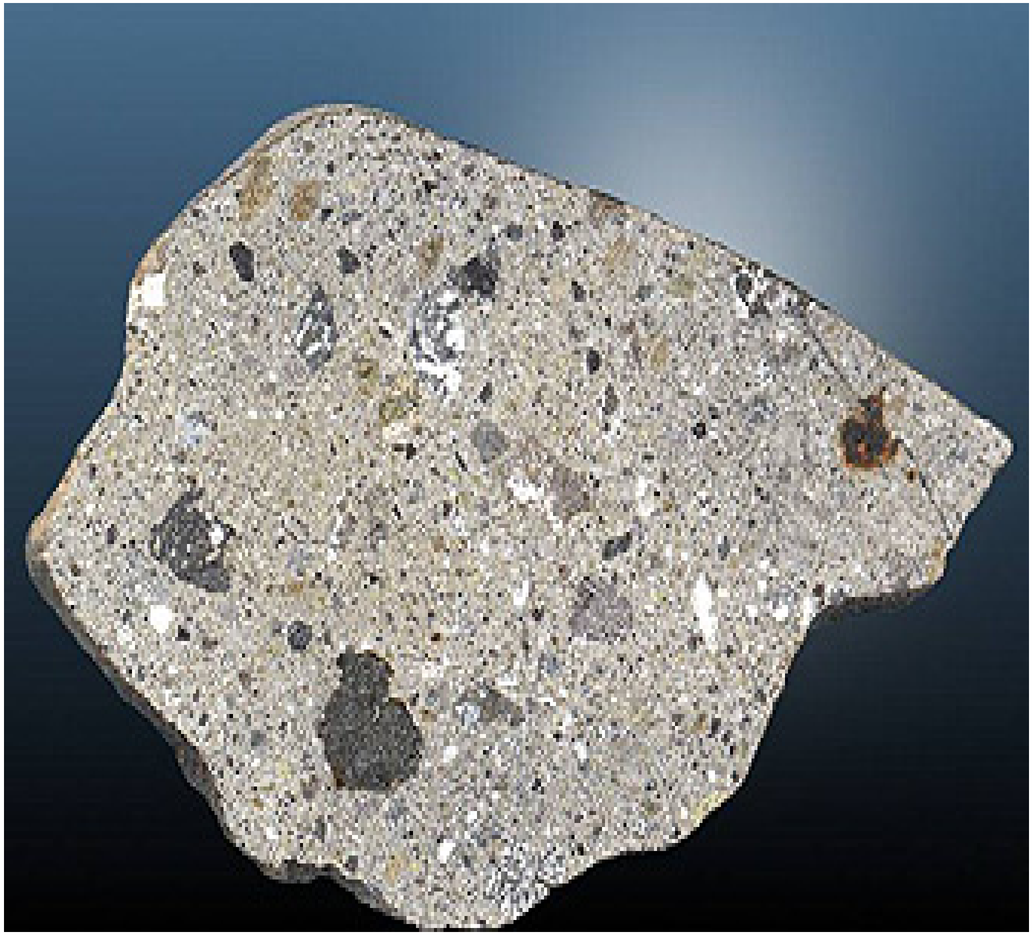


Photo image courtesy of NASA
http://rst.gsfc.nasa.gov/Sect19/Sect19_2.html

Review of Terminology …

- Impactor (projectile)

  Smallest of the two colliding bodies

- Target

  Object that is hit

- Impactite

  Shock metamorphosed rock

- Ejecta

  Glassy material and rock fragments thrown out of an impact crater during its formation

Review of Terminology …

Breccia:

- a rock consisting of angular fragments
- distinction is made among
    - Sedimentary
    - Tectonic
    - Volcanic
    - Hydrothermal

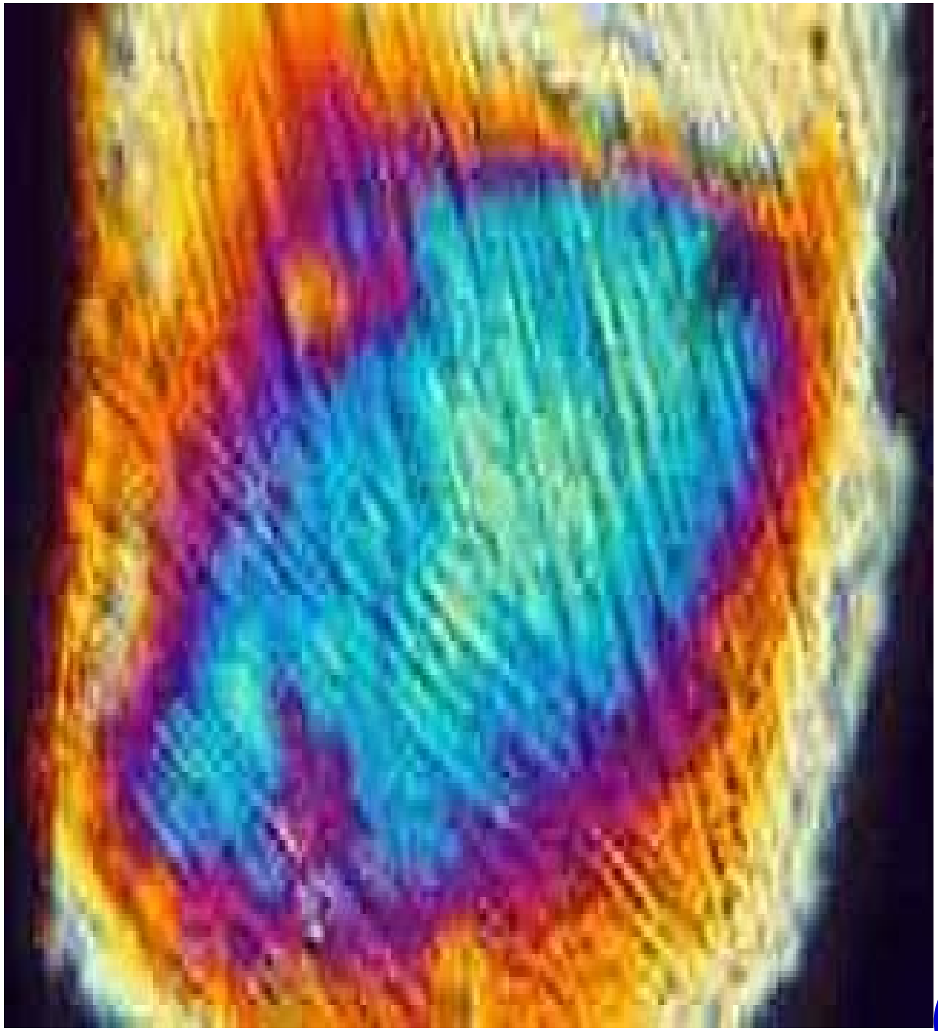
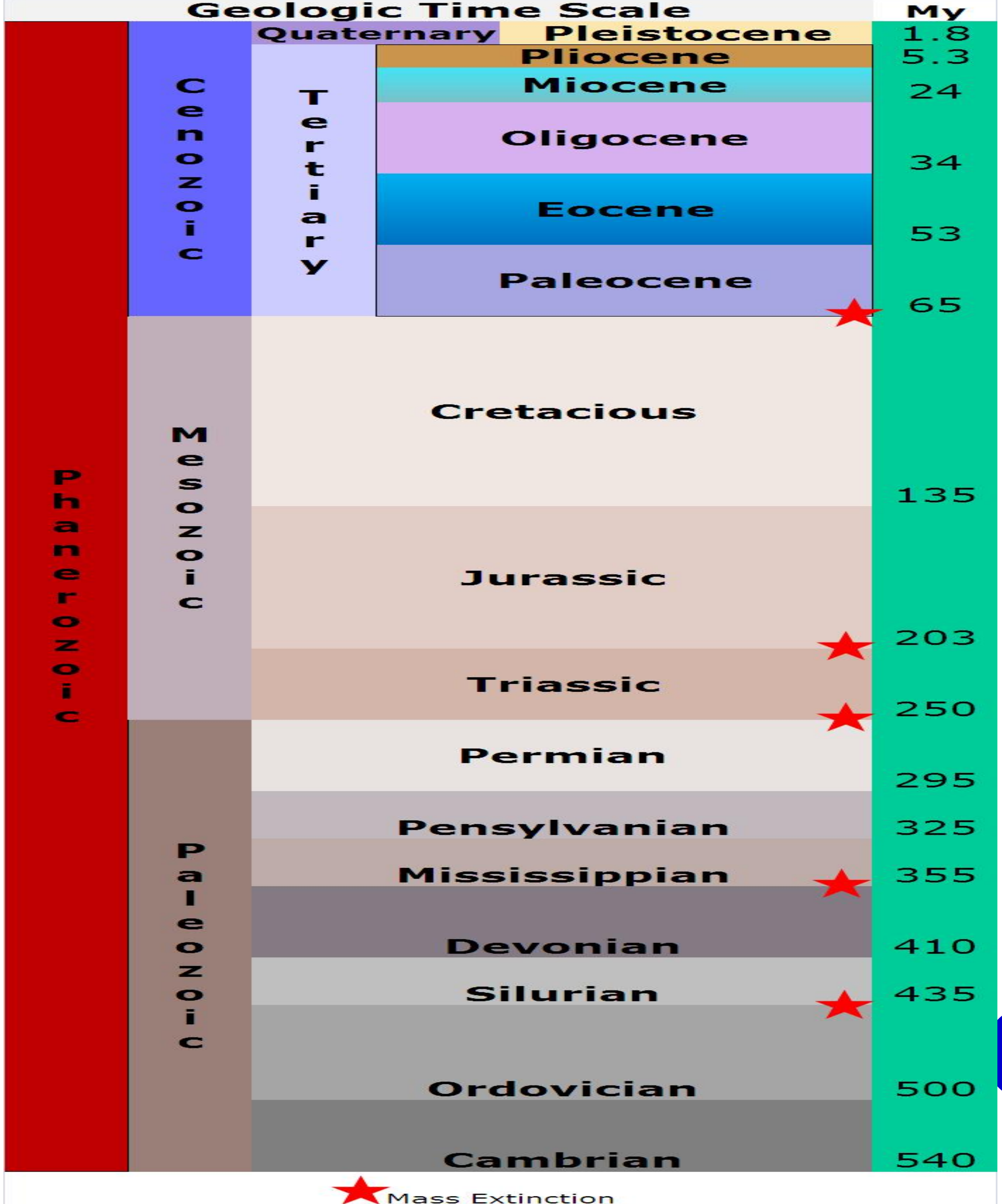


Photo image courtesy of NASA
http://rst.gsfc.nasa.gov/Sect18/h_impact_shocked_quartz_03.jpg

Review of Terminology …

Geologic Time Scale

Based on IUGS 2000



Review of Terminology …

PERIODIC TABLE OF ELEMENTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
3	11 Na 22.99	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.060	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.88	23 V 50.94	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.82	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	57 to 71	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.20	77 Ir 192.20	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.88	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn 222.02
7	87 Fr (223)	88 Ra 226.03	89 to 103	104 Rf 261.10	105 Db 262.11	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 Uub (285)		114 Uuq (289)		116 Uuh (289)		

Alkali Metals

Atomic Number → 27
Symbol → Co
Atomic Weight → 58.933

Noble Gases

Alkaline Earth Metals

Transition Metals

Solids

Gases

Liquids

Non Metals

Other Metals

57 to 71	Lanthanides	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
89 to 103	Actinides	89 Ac 227.03	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu 244.06	95 Am 243.06	96 Cm 247.07	97 Bk 247.07	98 Cf 251.08	99 Es 252.08	100 Fm 257.10	101 Md 258.10	102 No 259.10	103 Lr 262.11

Review of Terminology ...

Classification of elements-Geochemical

Grouping the elements according to their geochemical associations:

-phile means 'forming' or 'loving'.

Atmophile related to atmosphere.

Chalcophile - chalco means copper.

Lithophile – litho means stone – crustal.

Siderophile – sidero means iron.

Review of Terminology ...

CLASSIFICATION OF ELEMENTS - GEOCHEMICAL

Classification	Brief Characteristics	Main Elements
Atmophile	**Predominant in air**	**H, He, Hg, N, O and other noble gases and C (as CO_2)**
Chalcophile	**'Form sulfides, arsenides, selenides, tellurides; Sources of ore minerals for nonferrous metals'**	**Ag, As, Cd, Cu, Hg, Pb, S, Te, Zn**
Lithophile	**'Form silicates, aluminosilicates, oxides, carbonates, sulfates, halides, phosphates and vandates among other mineral forms in the natural environment'**	**Al, Ba, Ca, Cs, Li, K, Mg, Na, Rb, Sr, Th, U** **REE: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu**
Siderophile	**'Form alloys with iron and these are important sources of platinum group metals and gold'.**	**Au, C, Co, Fe, Ge, Mo, Ni, P, Pt, Sn**

Empirical means based on observation, valid information, not from theory

HISTORIC UNDERSTANDING OF CRATERS

Historically, the concept of impact cratering on earth is not given much consideration in classical geological studies.

According to the Huttonian and Lyellian classical geology, slow endogenic processes bring gradual geological changes.

Internal forces are given preferential consideration over more external processes for geological phenomena that appear occurring over very long periods of time.

Impact cratering appears as an exogenic, relatively rare, violent, and unpredictable event.

HISTORIC UNDERSTANDING OF CRATERS …

- **As Koeberl (1997) put**

“ It is almost ironical that it was Alfred Wegener who published a little-known study (Wegener, 1922), in which he concluded that the craters on the moon are of meteorite impact origin.

The history of study and acceptance of impact cratering over this century is somewhat similar to the record of the acceptance of plate tectonics. ”

NEED TO STUDY IMPACT CRATERS

- Impact cratering influences geological and biological evolution of the Earth
- Impact of relatively small asteroids or comets can have disastrous consequences for life on the Earth.
- The large and devastating ones occur less often than the small events

Well known example:

- Mass extinction event of 65 million years ago marking the Cretaceous-Tertiary boundary

Ref: **http://www.univie.ac.at/geochemistry/koeberl/**

Need to study impact craters …

- Impact crater studies provide clues to finding valuable resources such as water, minerals, ores.
- Impact hazards will be estimated and response preparation will be developed to minimize or avoid the hazard.
- Terrestrial impact cratering studies help modeling and understanding of other planetary craters.
- Multidisciplinary studies evolve and new technologies will be developed.

NEED TO STUDY IMPACT CRATERS …

- Large terrestrial impacts are of greater importance for the geologic history of our planet than the number and size of preserved structures might suggest.

For example, recent studies of the

- Cretaceous/Tertiary boundary, marking the abrupt demise of a large number of biological species including dinosaurs,

  revealed rare enrichments of siderophile elements - Sudbury nickel mine

TERRESTRIAL IMPACT CRATER IDENTIFICATION CRITERIA

The principal criteria for determining if a geological feature is an impact structure formed by the hypervelocity impact of a meteorite or comet are well explained by B.M. French (1998: Traces of Catastrophe) and also well given on the website of University of New Brunswick, Canada,

http://www.unb.ca/passc/ImpactDatabase/

are listed below.

The criteria can be satisfied by three analytical categories

- **Megascopic** view – bird's eye / satellite scale
- **Macroscopic** view with naked eye
- **Microscopic** view with instrumental help

TERRESTRIAL IMPACT CRATER IDENTIFICATION CRITERIA …

Earth has been even more heavily impacted than the Moon.

Terrestrial impact craters are continually erased by

- erosion by weathering
- redeposition
- volcanic resurfacing
- tectonic activity.

The physical markers disappear.

TERRESTRIAL IMPACT CRATER IDENTIFICATION CRITERIA …

- Certain terrestrial features generated by means other than impact can have comparable circular form, such as, by
  - volcanoes,
  - salt diapirs,
  - glacigenic features

  Hence, a circular structure alone is not sufficient to claim impact structure status.
- Buried terrestrial craters
  - Drill cores are required to reveal

TERRESTRIAL IMPACT CRATER IDENTIFICATION CRITERIA …

In general

Impact craters are geologic structures

Impact craters could be formed by impact of meteoroid or asteroid or comet into a planet

There has been heavy bombardment of all the planets and other bodies of the solar system.

The bombardment event is recorded and preserved for millions of years, on surfaces of planets like the Moon, Mars and Mercury because most geologic processes stopped there millions of years ago.

TERRESTRIAL IMPACT CRATER IDENTIFICATION CRITERIA …

The identification criteria are well listed on the web site of University of Newbrunswick

http://www.unb.ca/passc/ImpactDatabase/

1. Presence of shatter cones that are *in situ*
2. Presence of multiple planar deformation features (pdf) *in situ*
3. Presence of high pressure mineral polymorphs *in situ*

TERRESTRIAL IMPACT CRATER IDENTIFICATION CRITERIA …

shatter cones

Photo image courtesy of NASA
http://rst.gsfc.nasa.gov/Sect18/Sect18_4.html

TERRESTRIAL IMPACT CRATER IDENTIFICATION CRITERIA …

4. **Morphometry:**

Impact event causes changes in the impacted site, namely, creation of an impact crater. Impact craters could be visible to naked eye, as well as, may require sophisticated tools to map, especially, very large craters. In such cases, tools used are like

remote sensing,

aerial photography,

detailed mapping of multiple outcrops

to assemble and view the typically

km or multiple km-size structure.

Aerial image of shock metamorphism

Photo image courtesy of NASA

Terrestrial Impact Crater Identification Criteria …

Terrestrial Impact craters (before erosion) occur in two distinctly different morphological forms,

Simple craters

bowl-shaped craters with diameters

<=4 km to >=4 km

Complex craters

with a central uplift.

All craters have an outer rim and some crater infill such as brecciated and/or fractured rocks, impact melt rocks.

Central structural uplift in complex craters consists of a central peak or of one or more peak ring(s) and exposes rocks that are uplifted from considerable depth.

Terrestrial Impact Crater Identification Criteria …

- Figures as well as pictures of simple, complex consisting of single ring and multi-ring impact craters are well given in the literature and on the web.
- Some references are

1) Chapter 2: Crater Morphology

Chapter 9: Multiring Basins

in Impact Cratering – A geologic process by

Melosh (1989).

2) Chapter 3.2 : Simple and Complex Impact Structures

3.2.1. Simple Craters

3.2.2. Complex Craters

3.2.3. Multiring Basins

in Traces of Catastrophe – A handbook of Shock –Metamorphic Effects in Terrestrial Meteorite Impact Structures by B. M. French (1998).

Web References:

http://www.unb.ca/passc/ImpactDatabase/

http://rst.gsfc.nasa.gov/Sect18/Sect18_4.html

Terrestrial Impact Crater Identification Criteria …

- Complications of identifying terrestrial impact structures
- Factors that can obscure and/or destroy the original shape;.
  - burial processes
  - erosion
  - weathering,
  - tectonic deformation
- Thus, recognizing terrestrial impact structures solely by their morphometry is complicated.

Terrestrial Impact Crater Identification Criteria …

5. **Presence of impact melt sheet and/or dikes, impact melt breccias:**

specialized geochemical analysis required to detect the projectile components

- mapping and rock sampling, microscopic and geochemical analysis provide understanding of impact melt sheets generated by hypervelocity impact
- crustal composition typically gets derived by the fusion of target rocks without mantle contribution to the melt
- melt may contain meteoritic (projectile) components
- melt sheets may be covered by fallback "suevite" breccias
- material blasted out of the crater may form ejecta blankets about the original central cavity.
- large impact events may cause global fall out of ejecta

IMPACT CRATER BRECCIA

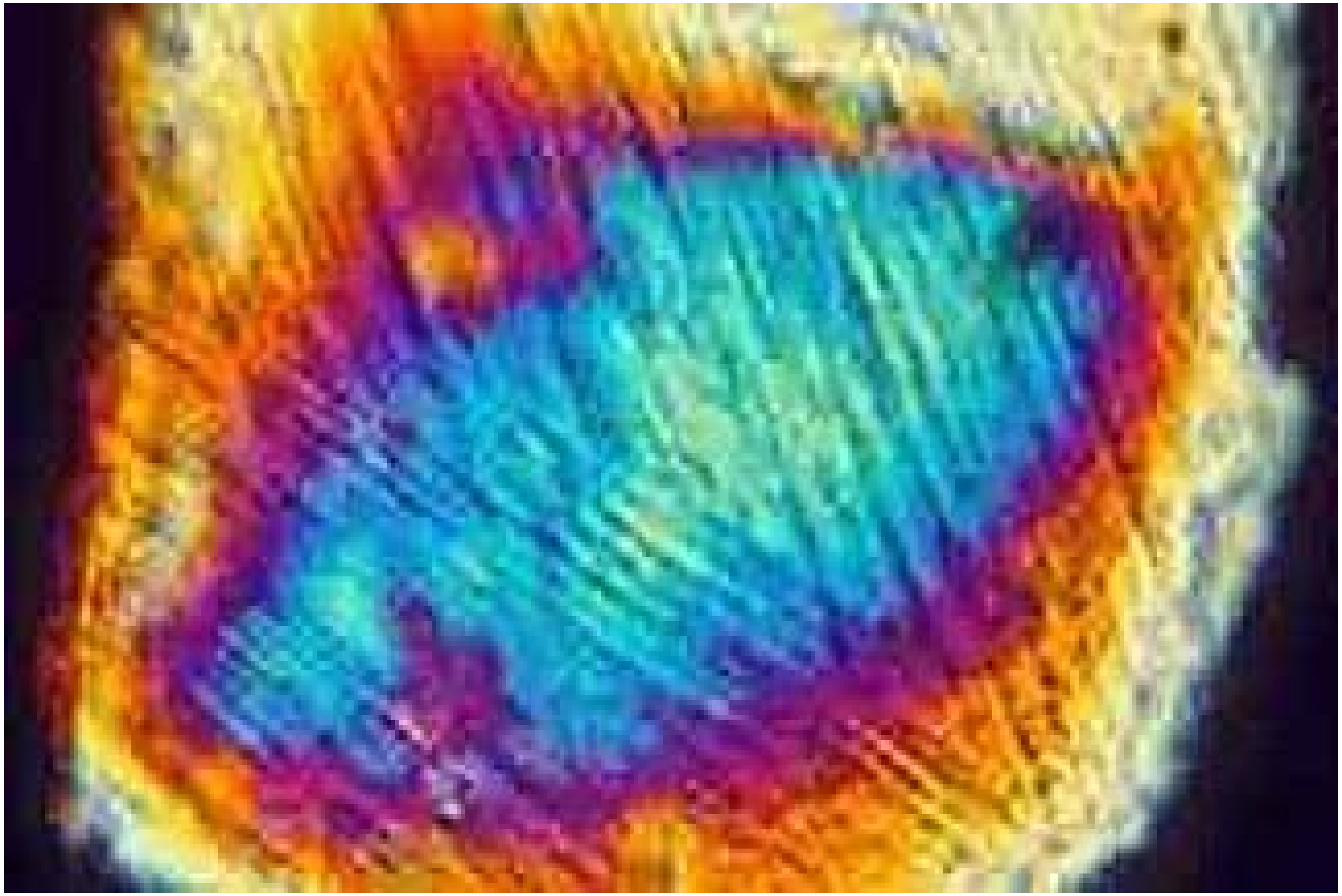


Photo image courtesy of NASA
http://rst.gsfc.nasa.gov/Sect18/h_impact_shocked_quartz_03.jpg

Terrestrial Impact Crater Identification Criteria …

6. Pseudotachylyte and Breccias as contributory evidence:

Pseudotachylyte is a metamorphosed rock, generated by faulting at microscopic/macroscopic scales.

Pseudotachylytes are also associated with

- seismic faulting due to endogenic processes
- earthquakes due to isostatic rebound and plate tectonics
- not exclusively by impact event

Excellent skill and experience are required for proper interpretation of breccias.

Terrestrial Impact Crater Identification Criteria Summary

1. Presence of shatter cones
2. Presence of multiple planar deformation features
3. Presence of high pressure mineral polymorphs
4. Presence of morphometric structures
5. Presence of impact melt sheets/dikes/melt breccias
6. Presence of pseudotchylytes and breccias

Terrestrial Impact Crater Identification Criteria Summary

<u>Definitive evidence</u>

1-3 above are considered definitive because of the passage of a shock wave caused by the projectile (impactor) through the target rock (Earth) and resulting modification processes.

<u>Contributory evidence</u>

_4-6 are consideredcontributory because they are results from secondary effects, like crater modification by gravitational effects.

<u>Buried structures</u> cannot be directly accessed,

but well-preserved are revealed by detailed geophysical techniques like seismic data.

Some consider this as strong evidence in favor of an impact origin.

TERRESTRIAL IMPACT CRATERS

The interest in impact craters is tremendously growing and new impact craters are getting investigated continuously.

The following tables provide informational exposure to some impact craters from different continents of the world.

Some Impact Craters of Africa

Crater Name	Loca-tion	Latitude	Longitude	Diameter km	Age My
Kgagodi	Bots-wana	S 22° 29'	E 27° 35'	3.5	< 180
Morokweng	South Africa	S 26° 28'	E 23° 32'	70	145.0 ± 0.8
Vredefort	South Africa	S 27° 0'	E 27° 30'	300	2023 ± 4

Based on http://www.unb.ca/passc/ImpactDatabase/africa.html

Some Impact Craters of Asia

Crater Name	Location	Latitude	Longitude	Diameter km	Age My
Jänisjärvi	Russia	N 61° 58'	E 30° 55'	14	700 ± 5
Kaluga	Russia	N 54° 30'	E 36° 12'	15	380 ± 5
Kamensk	Russia	N 48° 21'	E 40° 30'	25	49.0 ± 0.2
Kara	Russia	N 69° 6'	E 64° 9'	65	70.3 ± 2.2
Lonar	India	N 19° 58'	E 76° 31'	1.83	0.052 ± 0.006
Tabun-Khara-Obo	Mongolia	N 44° 07'	E 109° 39'	1.3	150 ± 20

Based on http://www.unb.ca/passc/ImpactDatabase/asia.html

Some Impact Craters of Australia

Crater Name	Location	Latitude	Longitude	Diameter km	Age My
Acraman	South Australia	S 32° 1'	E 135° 27'	90	~ 590
Amelia Creek	Australia	S 20° 55'	E 134 ° 50'	~20	1640 ± 600
Shoemaker (formerly Teague)	Western Australia	S 25° 52'	E 120° 53'	30	1630 ± 5
Strangways	Northern Territory	S 15° 12'	E 133° 35'	25	646 ± 42
Tookoonooka	Queensland	S 27° 7'	E 142° 50'	55	128 ± 5
Yarrabubba	Western Australia	S 27° 10'	E 118° 50'	30	~ 2000

Based on http://www.unb.ca/passc/ImpactDatabase/austr.html

Some Impact Craters of Europe

Crater Name	Location	Latitude	Longitude	Diameter km	Age My
Dobele	Latvia	N 56° 35'	E 23° 15'	4.5	290 ± 35
Gardnos	Norway	N 60° 39'	E 9° 0'	5	500 ± 10
Granby	Sweden	N 58° 25'	E 14° 56'	3	~ 470
Ilyinets	Ukraine	N 49° 7'	E 29° 6'	8.5	378 ± 5*
Keurusselkä	Finland	N 62° 8'	E 24° 36'	30	<1800
Mien	Sweden	N 56° 25'	E 14° 52'	9	121.0 ± 2.3
Ries	Germany	N 48° 53'	E 10° 37'	24	15.1 ± 0.1

Based on http://www.unb.ca/passc/ImpactDatabase/europe.html

Some Impact Craters of North America

Crater Name	Location	Latitude	Longitude	Diameter km	Age My
Ames	Oklahoma, U.S.A.	N 36° 15'	W 98° 12'	16	470 ± 30
Avak	Alaska, U.S.A.	N 71° 15'	W 156° 38'	12	Mar-95
Barringer	Arizona, U.S.A.	N 35° 2'	W 111° 1'	1.18	0.049 ± 0.003
Beaverhead	Montana, U.S.A.	N 44° 36'	W 113° 0'	60	~ 600
Brent	Ontario, Canada	N 46° 5'	W 78° 29'	3.8	396 ± 20
Carswell	Saskatchewan, Canada	N 58° 27'	W 109° 30'	39	115 ± 10
Charlevoix	Quebec, Canada	N 47° 32'	W 70° 18'	54	342 ± 15
Chesapeake Bay	Virginia, U.S.A.	N 37° 17'	W 76° 1'	90	35.5 ± 0.3
Chicxulub	Yucatan, Mexico	N 21° 20'	W 89° 30'	170	64.98 ± 0.05
Manicouagan	Quebec, Canada	N 51° 23'	W 68° 42'	100	214 ± 1
Sudbury	Ontario, Canada	N 46° 36'	W 81° 11'	250	1850 ± 3

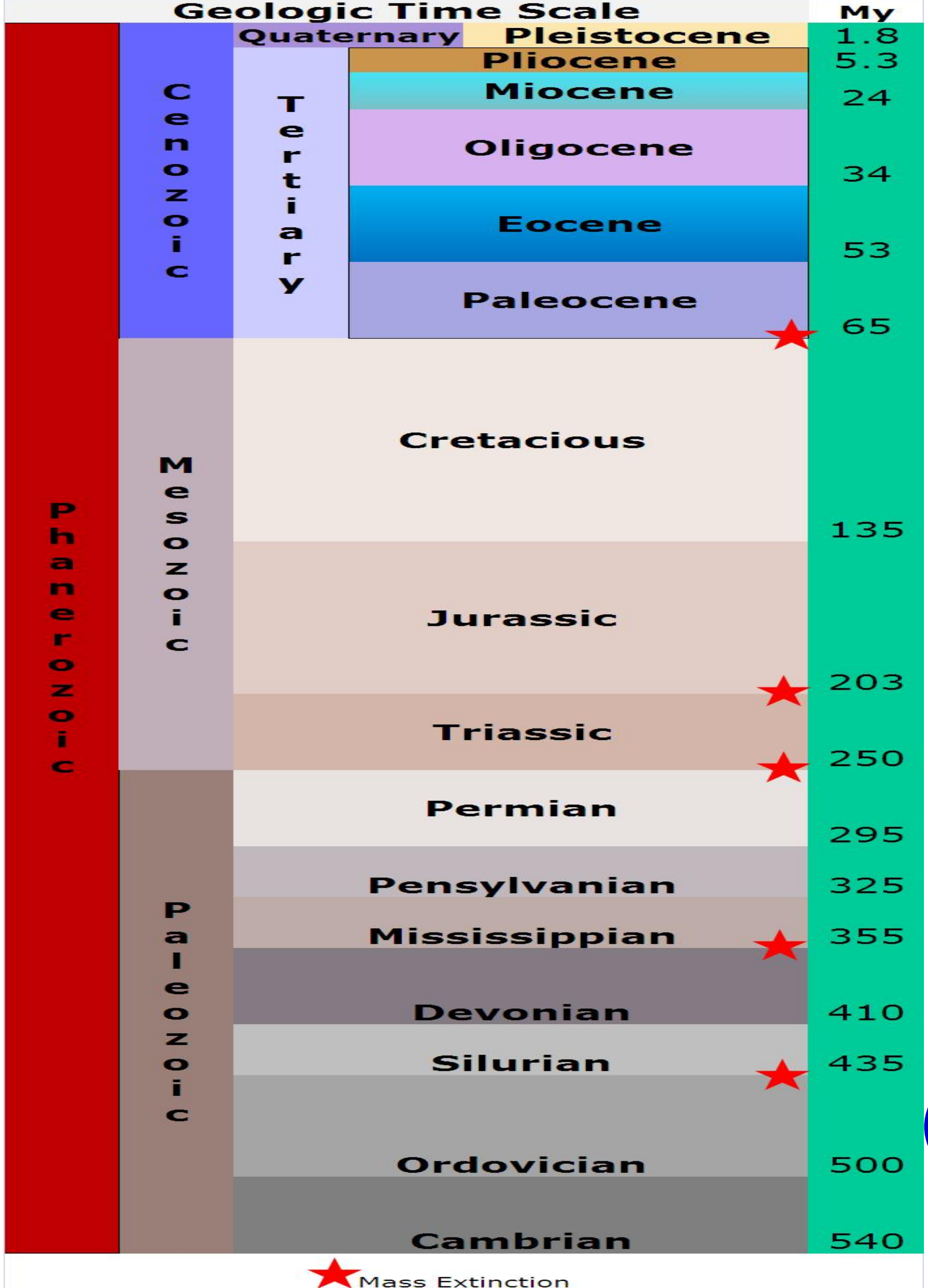
Based on http://www.unb.ca/passc/ImpactDatabase/NorthAmerica.html

Some Impact Craters of South America

Crater Name	Location	Latitude	Longitude	Diameter km	Age My
Campo Del Cielo	Argentina	S 27° 38'	W 61° 42'	0.05	< 0.004
Araguainha	Brazil	S 16° 47'	W 52° 59'	40	244.40 ± 3.25
Monturaqui	Chile	S 23° 56'	W 68° 17'	0.46	< 1

Based on
http://www.unb.ca/passc/ImpactDatabase/SAm.html

Geologic Time Scale based on IUGS 2000



Understanding Terrestrial Impact Event – A Summary

Scientific studies of terrestrial impact craters

- Geological studies
  - Geographic
  - Mineralogical
  - Petrographical
  - Geochemical
- Biological studies

  Investigate extinction events that correspond with celestial impacts.
- Earth Science studies

  The effects and changes on environment due to meteorite impacts.
- Computer Modeling
- Multidisciplinary Studies of impact craters

Understanding Terrestrial Impact Event – A Summary …

- Understanding of impact structures, their formation processes, and their consequences should be of interest not only to earth and planetary scientists, but also to society in general.
- The biological evolution of planets is punctuated by mass extinction events, the well known, 65 million years ago at the Cretaceous-Tertiary boundary.
- Abundant impact debris marks this boundary, providing a clear link with a major impact event. The Chicxulub impact structure of 200 km diameter, in Mexico, resulted from the impact of an about 10-km-diameter asteroidal body. This event has been identified as the main reason.

Understanding Terrestrial Impact Event – A Summary …

Several other mass extinctions such as

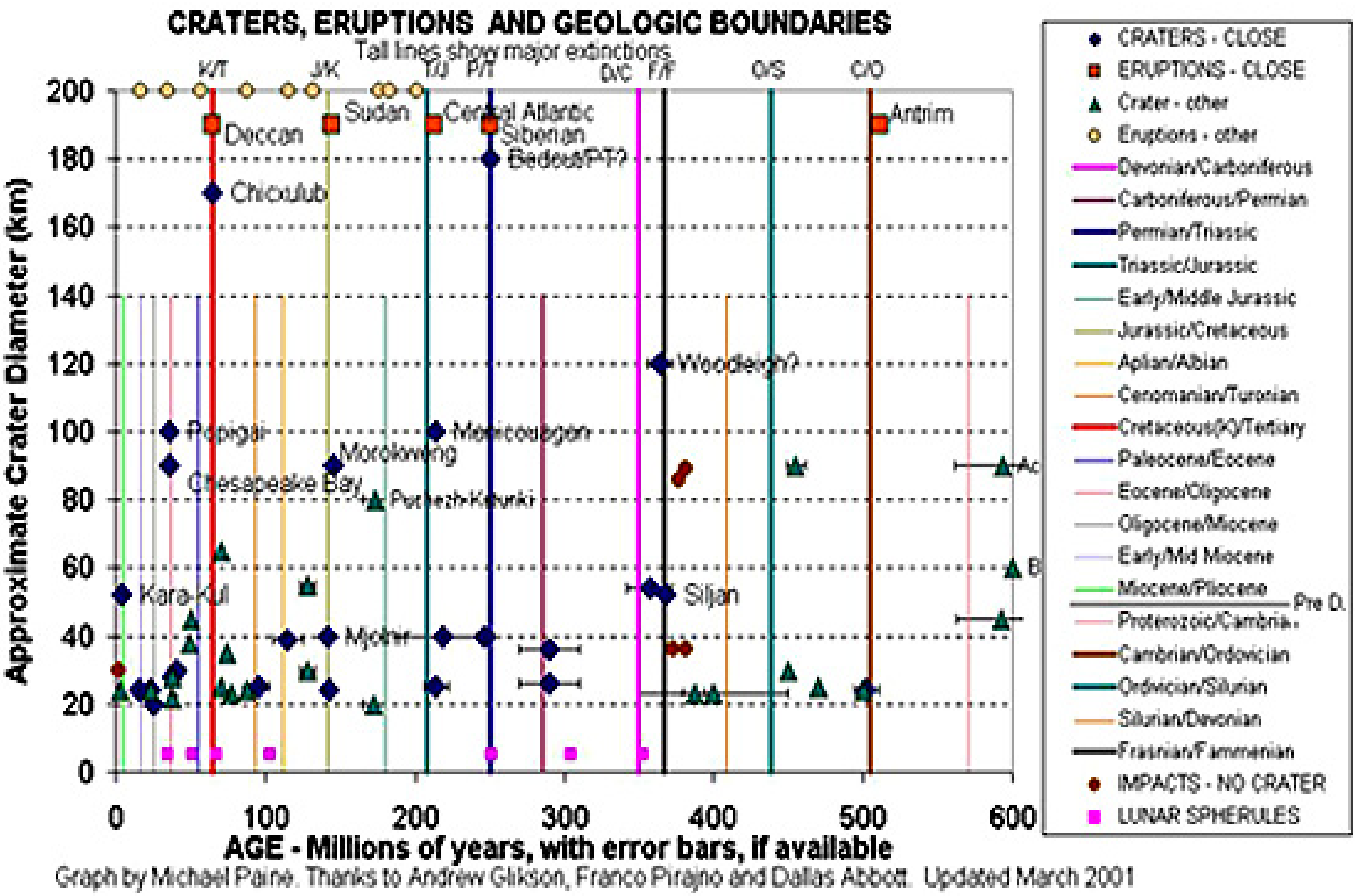
- Late Devonian (355 Ma)
- Permian-Triassic (250 Ma)
- Triassic-Jurassic (203 Ma)
- Jurassic-Cretaceous ?? (135 Ma)

may be linked to possible impact events as well, although in these cases the evidence is not strong enough currently.

Understanding Terrestrial Impact Event – A Summary …

- There is a 1 in 10,000 chance that a large asteroid or comet 2 km in diameter (corresponding to a crater of about 25-50 km in diameter) may collide with the Earth during the next century, severely disrupting the ecosphere and annihilating a large percentage of the Earth's population.
- But with constant monitoring of the space these asteroids can be intercepted and the catastrophe may be avoided.

Geologic Age Distribution of
Craters , Volcanic Eruptions, Mass Extinctions



Graphic image courtesy of NASA
http://rst.gsfc.nasa.gov/Sect18/Sect18_4.html
Nicholas M. Short, Sr.

IAP 2008 – 12.091 Assignment 1

1. There are excellent web sites providing superb graphics about terrestrial impact craters.

   View images of few terrestrial craters and write a brief review of their characteristics.

Suggested sites:

1) University of New Brunswick, Canada

http://www.unb.ca/passc/ImpactDatabase/

2) Data Base of Terrestrial Impact Structures

http://www.lpi.usra.edu/publications/slidesets/craters/crater_index.shtml

Choose one terrestrial crater of your interest

Start literature survey about that crater.

You will be writing and presenting a report of that crater in our 5th session.

IAP 2008 – 12.091 Assignment 1 …

2. Review the classification of rocks.
   Write brief summary of your understanding

3. Review the Chart of Nuclides
   i. List the following:
      PGE: Platinum Group Elements
      REE: Rare Earth Elements
   ii. Give details of Atomic Number, Neutron number, Mass number and Half-life (where applicable) of the following isotope groups.
      ^{207}Pb, ^{206}Pb, ^{204}Pb
      ^{87}Sr, ^{86}Sr, ^{87}Rb
      ^{143}Nd, ^{144}Nd, ^{147}Sm
      ^{39}K, ^{40}K, ^{41}K
      ^{36}Ar, ^{38}Ar, ^{40}Ar

References for Further Reading

- Impact Cratering On Earth
- http://www.lpl.arizona.edu/impacteffects/

- Data Base of Terrestrial Impact Structures
- http://www.unb.ca/passc/ImpactDatabase/

- When the sky fell on our heads
- http://www.agu.org/revgeophys/claeys00/claeys00.html

- Terrestrial Impact Craters
- http://www.lpi.usra.edu/publications/slidesets/craters/crater_index.shtml

- Thinking about impact cratering
- http://www.lpl.arizona.edu/SIC/impact_cratering/
- http://deepimpact.jpl.nasa.gov/designing_craters/2think/tg_thinking_about_cratering.pdf

References for Further Reading …

- **Terrestrial impact craters**

  Calvin J. Hamilton

- **Terrestrial Impact Structures by**

  James D. Rupert

  (Canada Geological Survey), providing:

  - **an introduction on impact cratering on Earth (morphology, identification, hazard)**
  - **list of impact structures, with location, age, diameter and images (pictures, gravity maps)**

References for Further Reading …

- Remote Sensing Tools Chapter 18: Impact Cratering, Shock Metamorphism

  Primary Author: Nicholas M. Short, Sr.

  http://rst.gsfc.nasa.gov/Sect18/Sect18_3.html

  http://rst.gsfc.nasa.gov/Sect18/Sect18_4.html

- Terrestrial Impact Craters

  Koeberl, C., and V. L. Sharpton, V. L.

  http://www.lpi.usra.edu/publications/slidesets/impacts.html

References for Further Reading …

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References for Further Reading …

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  The Cretaceous/Tertiary boundary impact (or the dinosaurs didn't have a chance):
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  v. 87, p. 77-118, 1993.
- Kelley, S.,
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- Melosh, H.J.,
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References for Further Reading …

- **Pilkington, M. and Grieve, R. A. F. , 1992, The Geophysical Signature of Terrestrial Impact Craters.** ***Reviews of Geophysics, May 1992, v. 30, pp. 161-181.***

- **Eds: Roth, E., Poty, B., Menager, M-T.,** ***Nuclear Methods of Dating*** **, pgs. 600, Kluwer Academic Publishing © 1989**
  ISBN 0792301889

Keywords

- Asteroids, meteoroids, meteorites, chondrites, breccia, impact cratering, impactor, impactite

Session 1
End