Examples and Consequences of NEA Impacts

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THE NEWS OF FRIDAY, FEBRUARY 15, 2013

Headline:

Small asteroid penetrates Earth's atmosphere

& catastrophically disrupts over Russia

Reasonable (predictive) questions:

Was it an ordinary chondritic asteriod? Yes

Was it internally brecciated? Yes

Was it cross-cut with shock veins? Yes

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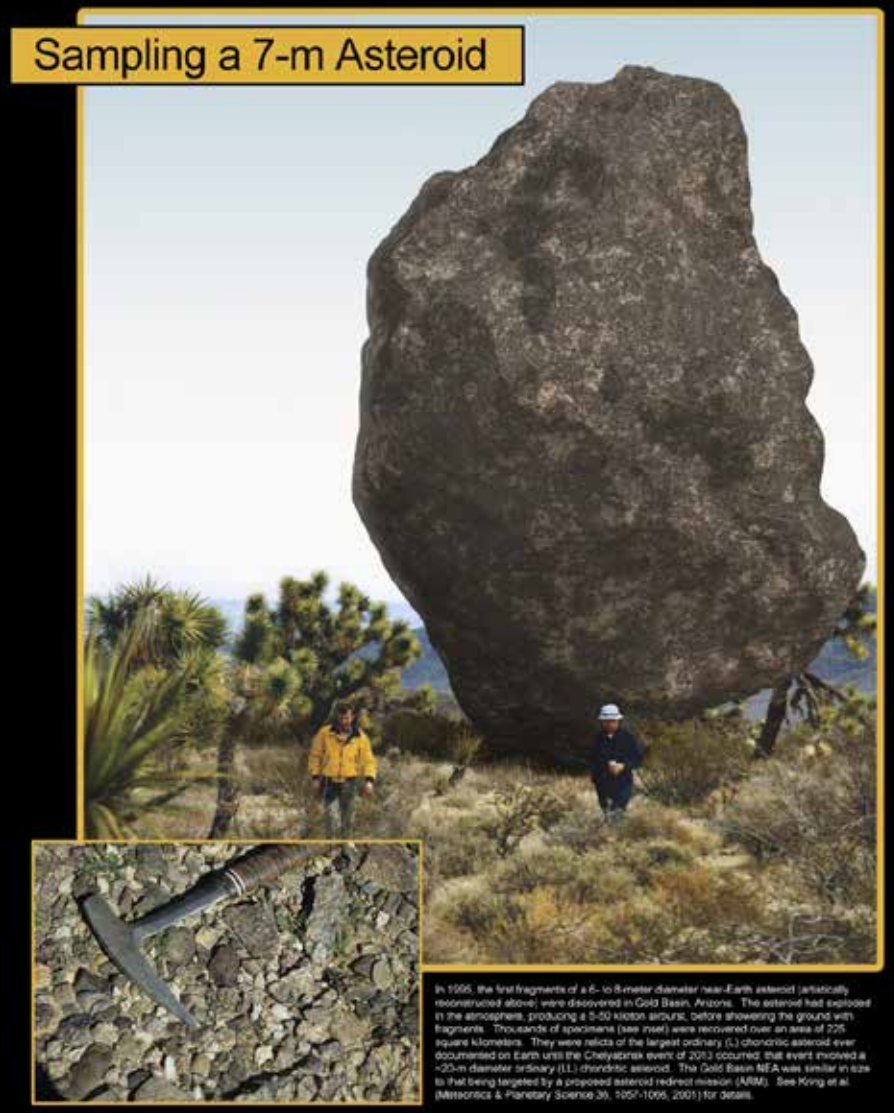
EXPLOSIVE FRAGMENTATION OF SMALL STONY ASTEROIDS

Map by Bailey & Kring/LPL/UA

The Gold Basin, Arizona, Event
~20,000 years ago
See Kring et al. (2001)

Previously, the largest documented explosive fragmentation of an ordinary chondritic asteroid occurred over northwestern Arizona in the Gold Basin area.

EXPLOSIVE FRAGMENTATION OF SMALL STONY ASTEROIDS



That event involved an ~7-meter diameter NEA with the kinetic energy equivalent to 5 to 50 kt of TNT.

(This object is similar in size to that being targeted by ARM.)

Several thousand relics of the asteroid were found in the desert, from which an artistic reconstruction was produced (left).

See Kring et al. (2001) for details.

Fragmentation is common for NEA of this size and type of material.

SMALL IMPACT CRATERS ARE DOMINATED BY IRON ASTEROIDS

Table 8.3. Small (≲1 km) diameter impact pits and impact craters.

Crater	Locality	Diameter (km)	Projectile	Age (Ma)
Haviland	Kansas, USA	0.011	Pallasite	0
Dalgaranga	Western Australia, Australia	0.021	Mesosiderite	0.025
Sikhote Alin	Primorskiy Kray, Russia	0.027	IIAB	0
Campo del Cielo*	Gran Chaco Gualamba, Argentina	0.05	IAB	<0.004
Sobolev	Primorye Territory, Russia	0.053	Iron	0
Veevers	Western Australia, Australia	0.08	IIAB	<1
Ilumetsa	Estonia	0.08	?	>0.002
Wabar*	Rub' al Khali, Saudi Arabia	0.097	IIIAB	0.006 ± 0.002
Morasko*	Poznan, Poland	0.1	IAB	0.01
Kaalijarvi*	Saaremaa, Estonia	0.11	IAB	0.004 ± 0.001
Henbury*	Northern Territory, Australia	0.157	IIIAB	<0.005
Odessa*	Texas, USA	0.168	IAB	<0.05
Boxhole	Northern Territory, Australia	0.17	IIIAB	0.03
Macha*	Russia	0.3	Iron	<0.007
Aouelloul	Adrar, Mauritania	0.39	Iron or Pallasite	3.1 ± 0.3
Amguid	Algeria	0.45	?	<0.1
Monturaqui	Antofagasta, Chile	0.46	IAB	<1
Kalkkop	South Africa	0.64	?	<1.8
Wolfe Creek	Western Australia, Australia	0.87	IIIAB	<0.3
Tswaing	South Africa	1.13	Chondrite	0.220 ± 0.052
Barringer	Arizona, USA	1.19	IAB	0.049 ± 0.003

Compiled from Grieve (1991), Grieve et al. (1995), Koeberl et al. (1994), and Koeberl et al. (1998).
*Crater field; diameter of largest crater listed.

Table from Kring (2007)

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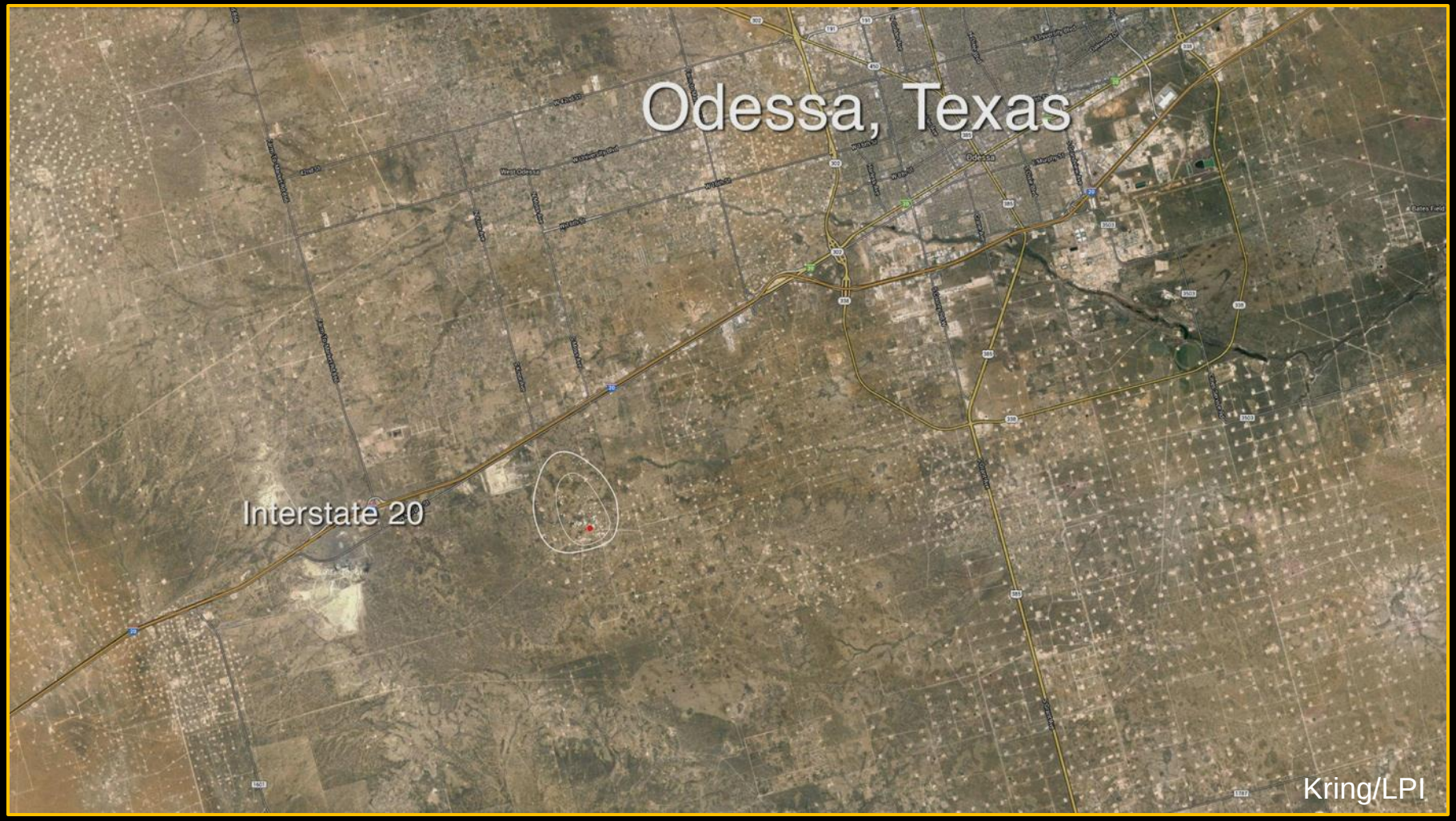
ODESSA IMPACT CRATER FIELD, WEST TEXAS

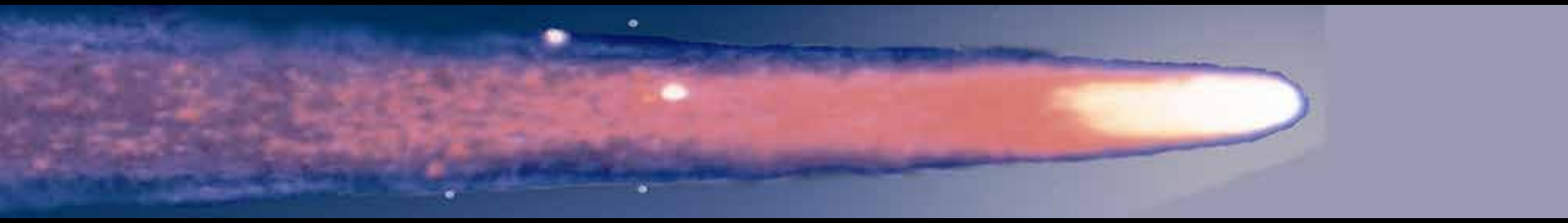
ODESSA IMPACT CRATER FIELD, WEST TEXAS



ODESSA IMPACT CRATER FIELD, WEST TEXAS

Main crater produced by iron NEA fragment ~2 to 4 meters in diameter.

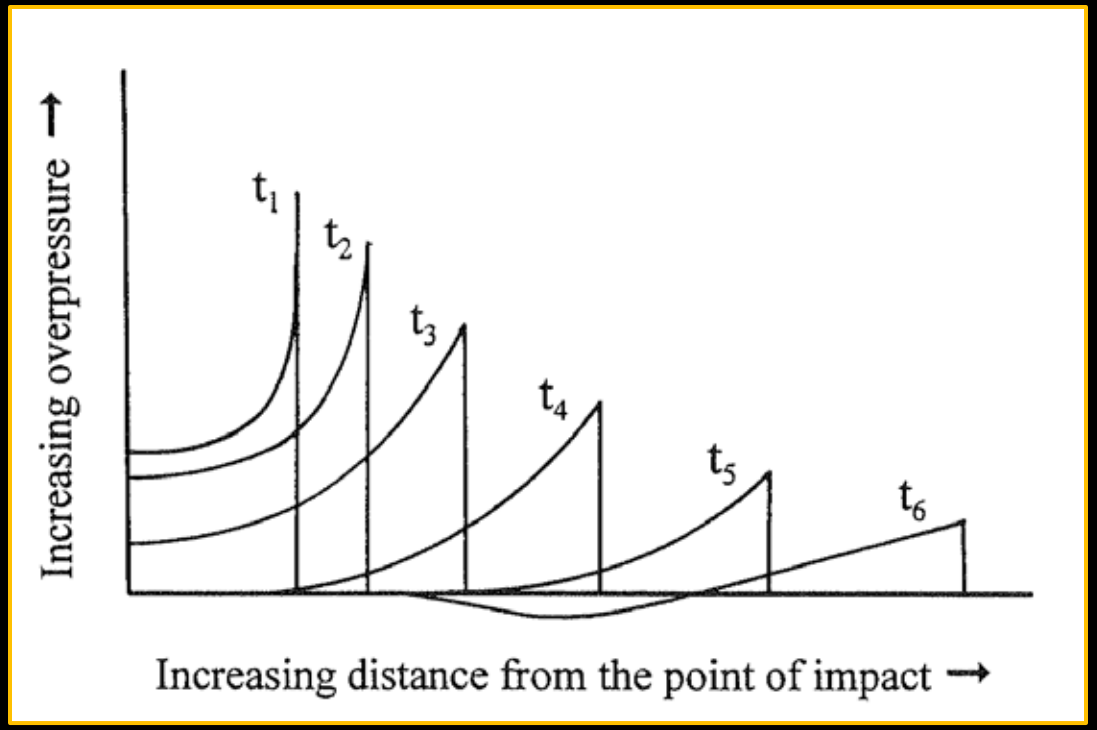
COMPONENTS OF IMPACT AIR BLASTS



- Shock waves are produced by objects moving faster than the speed of sound (i.e., Mach 1). Impacting NEAs penetrate the atmosphere with a speed equal to or in excess of 11.2 km/s (≥25,000 mph or ≥ Mach 35), producing a ballistic shock wave. The Chelyabinsk NEA was moving at Mach 60 to 61.
- A second, explosive shock wave, is produced when the object catastrophically fragments in the atmosphere or hits the surface to produce an impact crater
- The shock waves are accompanied by high-velocity air blasts

- Similar effects were measured around nuclear explosion test sites

COMPONENTS OF IMPACT AIR BLASTS



Schematic diagram illustrating the variation of overpressure in air at successive times (t_1, t_2, etc.) as a function of distance. Figure 1 of Kring (1997); after Glasstone and Dolan (1977).

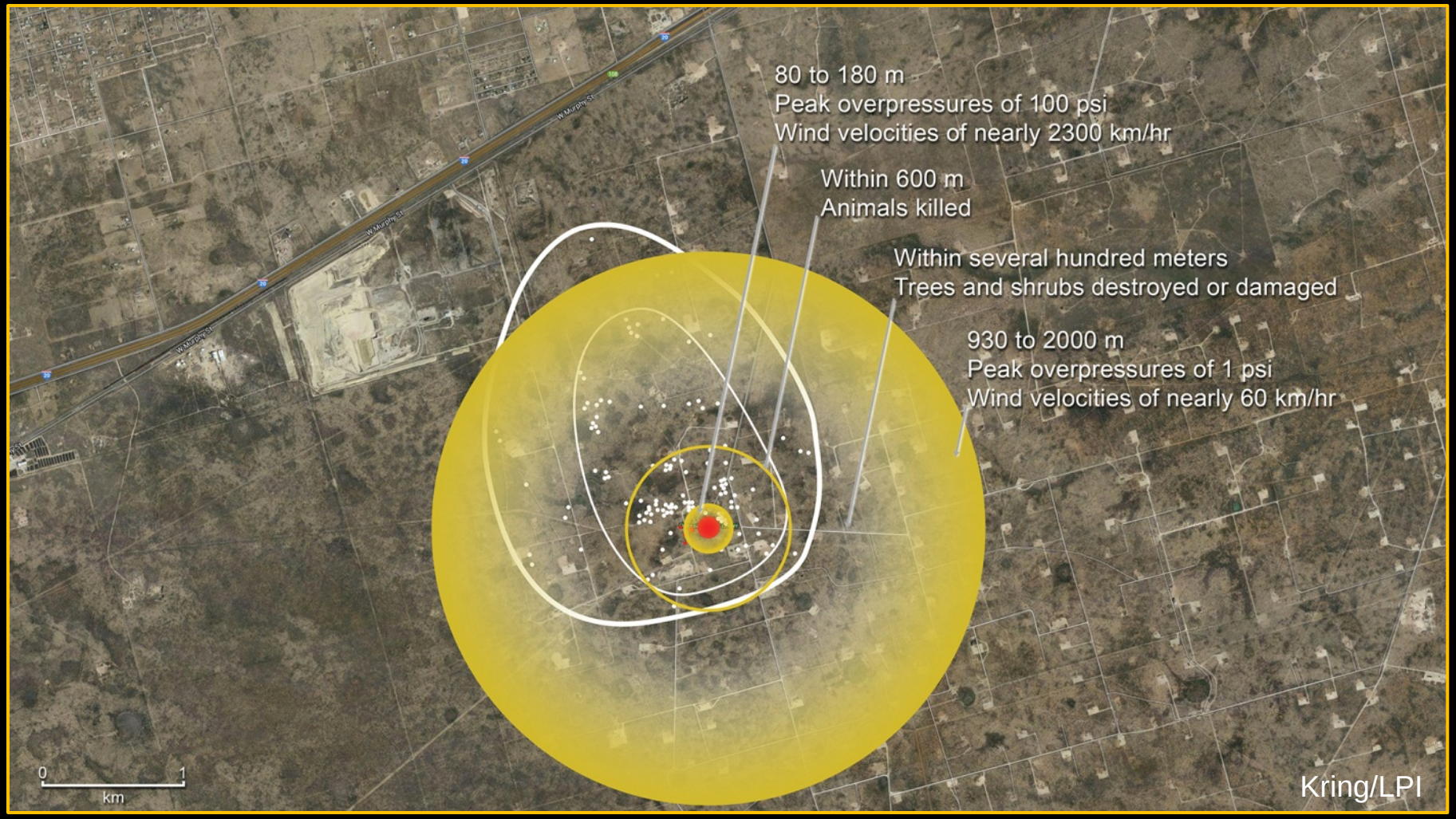
Shock overpressures

An explosive fragmentation event or a cratering event produces a blast wave that radiates outward.

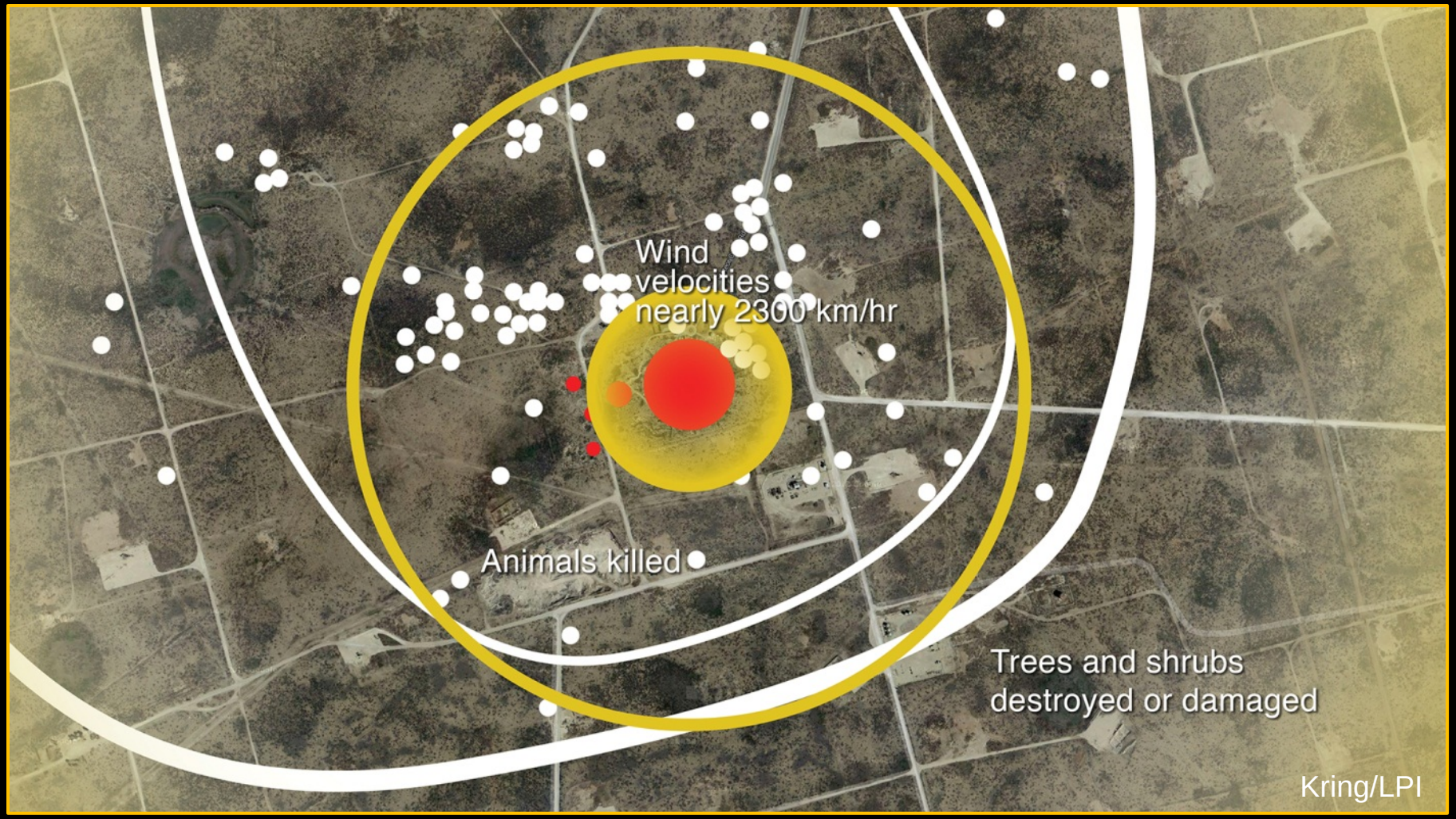
At any particular point, the pressure increases nearly instantaneously when the shock front arrives.

The pressure produced by a shock front is usually characterized in terms of overpressure, which is the amount of pressure that exceeds ambient atmospheric pressure (14.7 psi for standard sea level conditions).

ODESSA IMPACT CRATER FIELD, WEST TEXAS



ODESSA IMPACT CRATER FIELD, WEST TEXAS



BARRINGER METEORITE CRATER (aka METEOR CRATER), ARIZONA

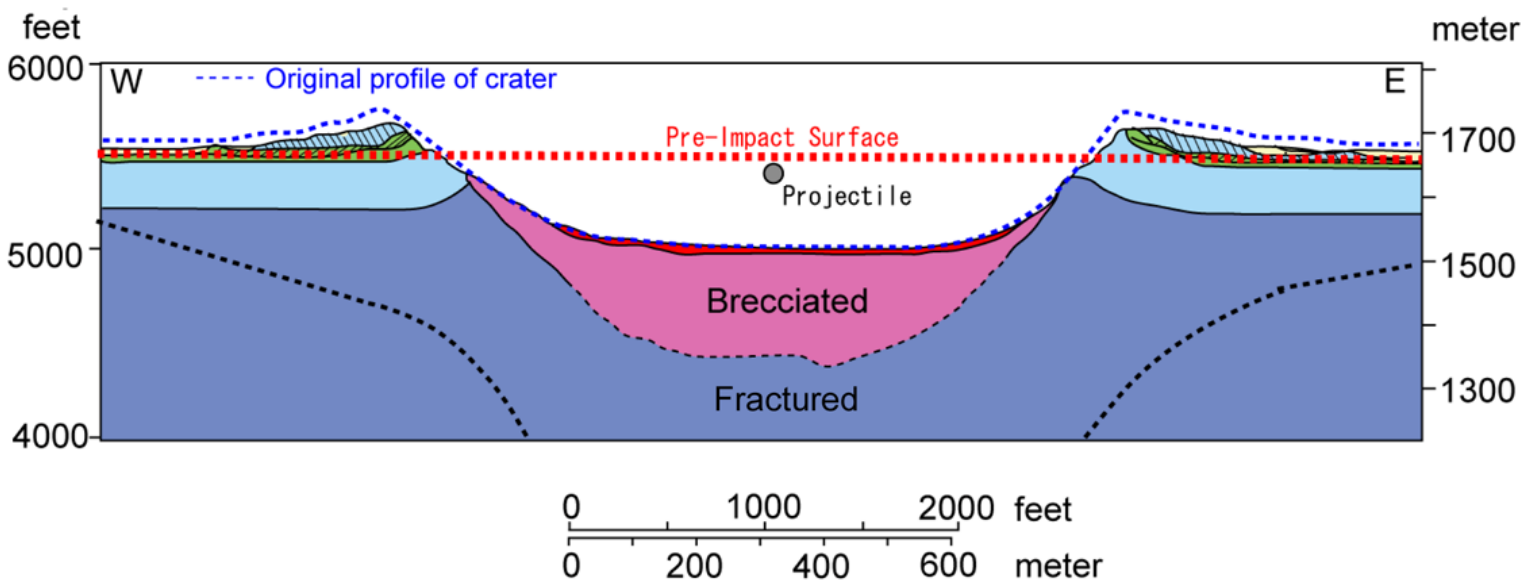
CASE STUDY OF AN IMPACT AIR BLAST – BARRINGER (METEOR) CRATER

Photograph © David A. Kring

Video available for download from
http://www.lpi.usra.edu/publications/books/barringer_crater_guidebook/flyover/

CASE STUDY OF AN IMPACT AIR BLAST – BARRINGER (METEOR) CRATER

Relative Scale of Iron NEA and the Excavated Crater



Niihara and Kring (2011)

- 175 million metric tons of rock were excavated in a brief geologic moment
- The horizontal layers of the upper Grand Canyon sequence were uplifted dramatically in the crater walls
- A portion of the Earth's crust was also vaporized, melted, and heavily fractured

WHEN A NEWSPAPER REPORTS AN ASTEROID BEING TWO TIMES LARGER

Stony asteroid
20 meters diameter

Asteroid art by Daniel D. Durda

WHEN A NEWSPAPER REPORTS AN ASTEROID BEING TWO TIMES LARGER

"2 times larger"

Stony asteroid
20 meters diameter

Stony asteroid
40 meters diameter

Asteroid art by Daniel D. Durda

WHEN A NEWSPAPER REPORTS AN ASTEROID BEING TWO TIMES LARGER

"2 times larger"

Stony asteroid
20 meters diameter

Stony asteroid
40 meters diameter

8 times larger volume
8 times larger mass

Asteroid art by Daniel D. Durda

WHEN A NEWSPAPER REPORTS AN ASTEROID BEING TWO TIMES LARGER

Stony asteroid
20 meters diameter

"2 times larger"

Stony asteroid
40 meters diameter

"2 times larger"

Iron asteroid
40 meters diameter

8 times larger volume
8 times larger mass

Left and center asteroids by Daniel D. Durda

WHEN A NEWSPAPER REPORTS AN ASTEROID BEING TWO TIMES LARGER

Stony asteroid
20 meters diameter
Density = 2 g/cm^3

"2 times larger"

Stony asteroid
40 meters diameter
Density = 2 g/cm^3

8 times larger volume
8 times larger mass

"2 times larger"

Iron asteroid
40 meters diameter
Density = 7 g/cm^3

8 times larger volume
28 times larger mass

Left and center asteroids by Daniel D. Durda

WHEN A NEWSPAPER REPORTS AN ASTEROID BEING TWO TIMES LARGER

Left and center asteroids by Daniel D. Durda

Stony asteroid
20 meters diameter
Density = 2 g/cm^3

KE ~ 500 kt
(Chelyabinsk)

"2 times larger"

Stony asteroid
40 meters diameter
Density = 2 g/cm^3

8 times larger volume
8 times larger mass

KE ~ 4 Mt

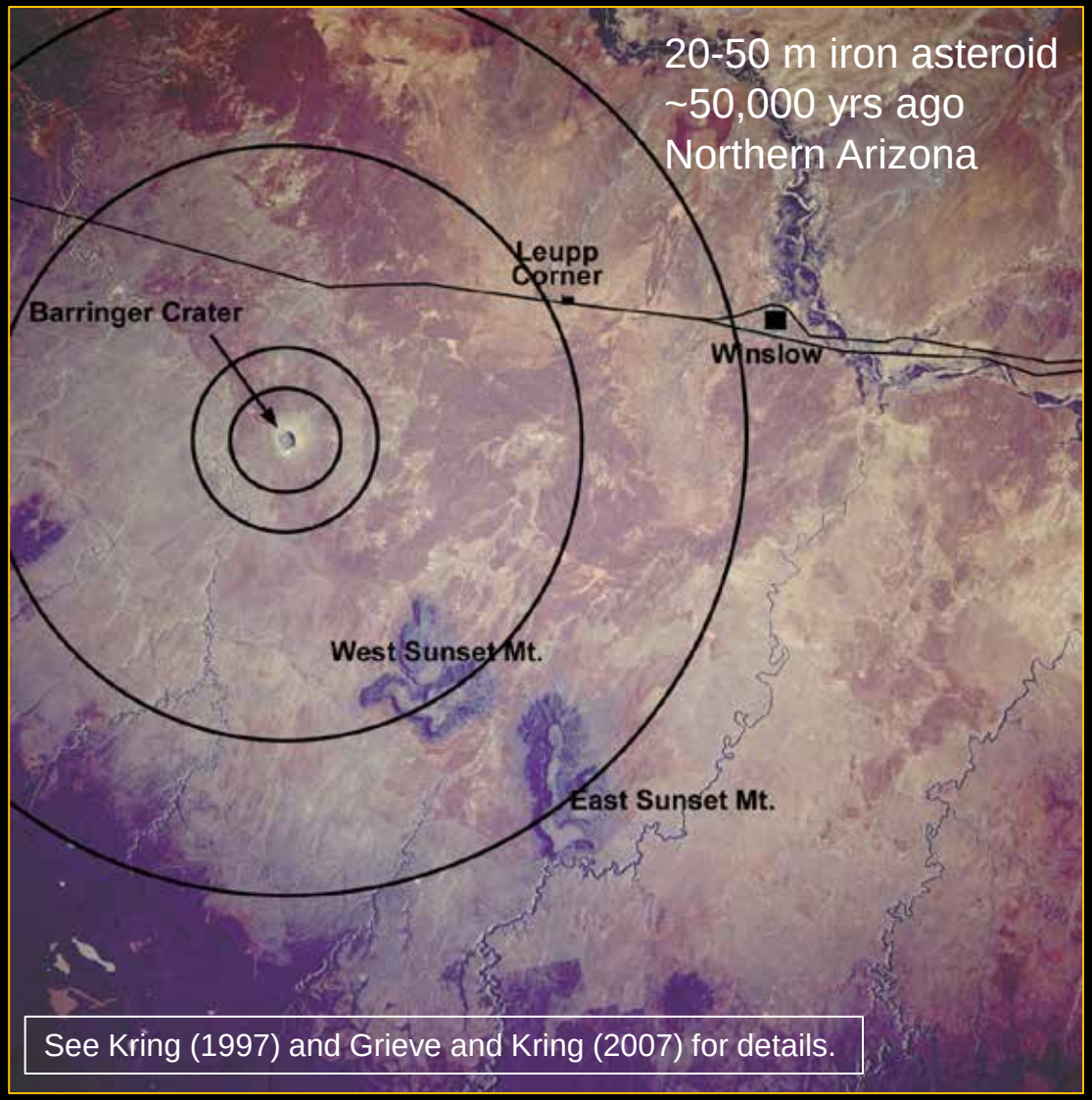
"2 times larger"

Iron asteroid
40 meters diameter
Density = 7 g/cm^3

8 times larger volume
28 times larger mass

KE ~ 14 Mt
(Meteor Crater)

CASE STUDY OF AN IMPACT AIR BLAST – BARRINGER (METEOR) CRATER



See Kring (1997) and Grieve and Kring (2007) for details.

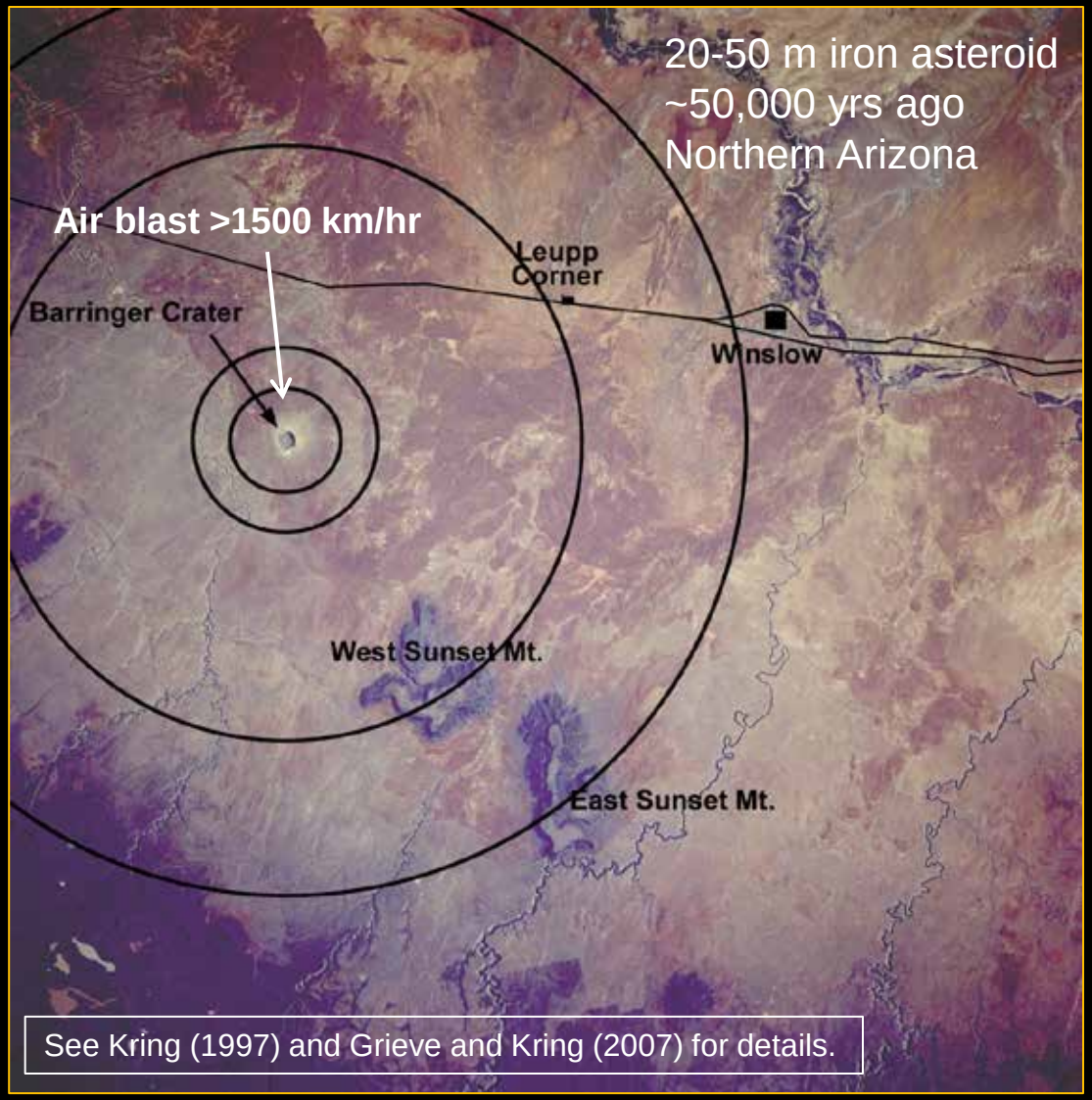
Small cratering events

In small events, a fireball, shock wave, and airblast are the major environmental effects.

The blast effect was immediately lethal for human-sized animals within the inner 6 km diameter circle.

Severe lung damage would occur within the next 10-12 km diameter circle due to the pressure pulse alone and animals would be severely injured and unlikely to survive.

CASE STUDY OF AN IMPACT AIR BLAST – BARRINGER (METEOR) CRATER



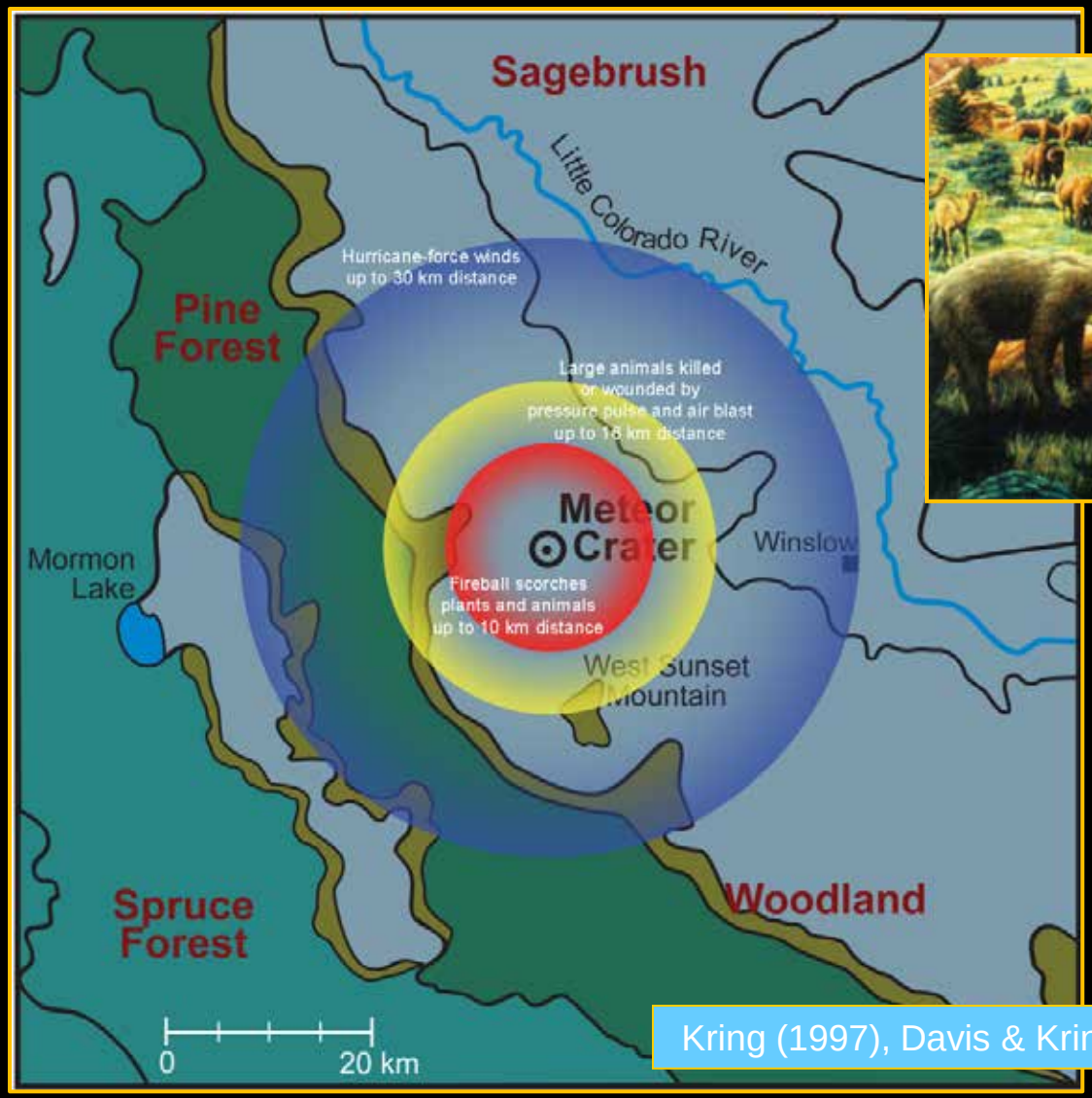
See Kring (1997) and Grieve and Kring (2007) for details.

Small cratering events

Winds would exceed 1500 km/hr within the inner circle and still exceed 100 km/hr at radial distances of 25 km (3rd circle).

The outermost ~50 km circle represents the outer limit of severe to moderate damage to trees and human-structures of comparable strength.

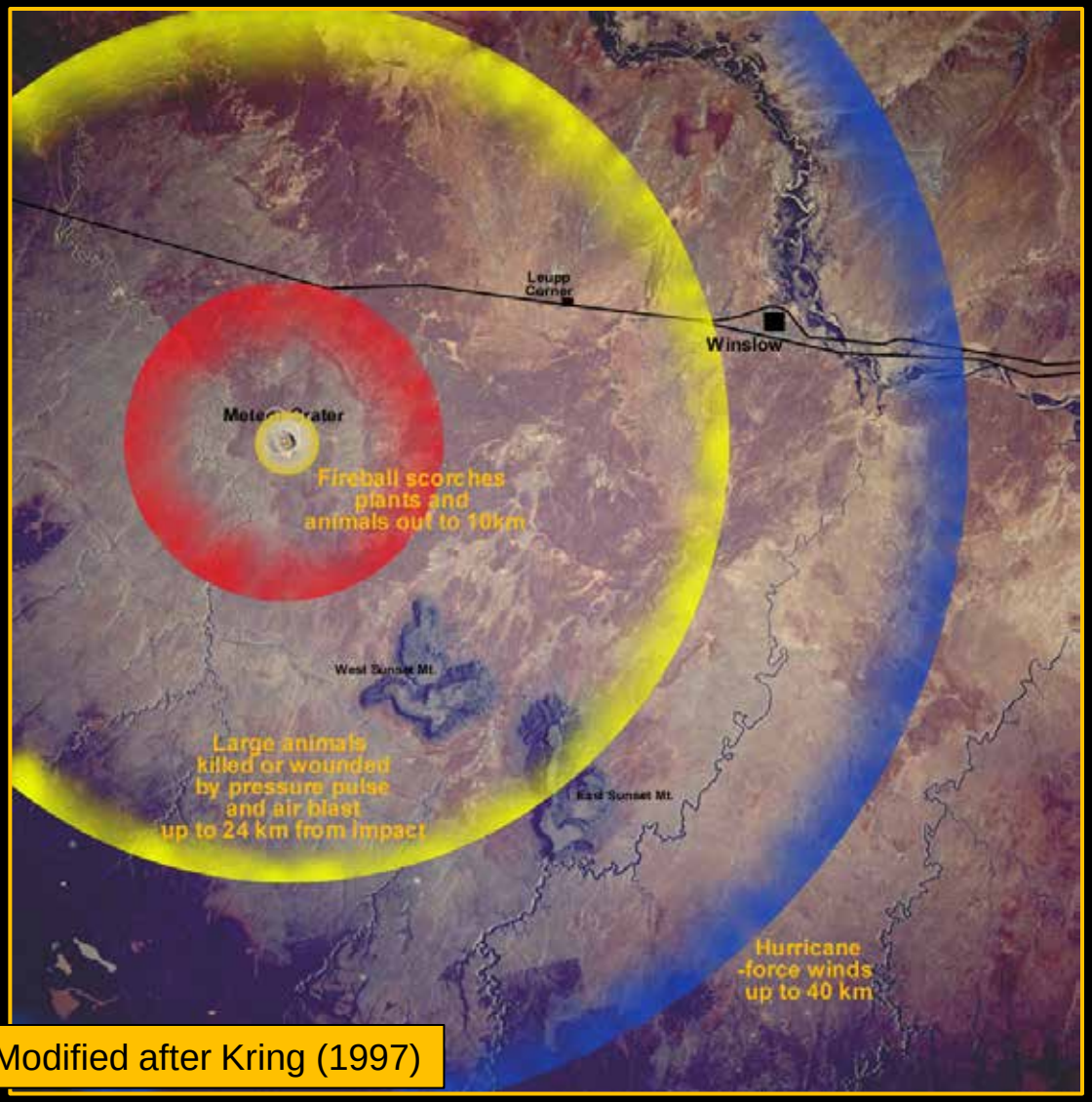
LETHAL EFFECTS OF SHOCK WAVE AND AIR BLAST



Painting by © Denny Carley, based on paleontological research by Larry Agenbroad and Jim Mead

Kring (1997), Davis & Kring (2000), Kring (2007)

COMPARING THE BLAST EFFECTS OF ODESSA AND BARRINGER CRATERS



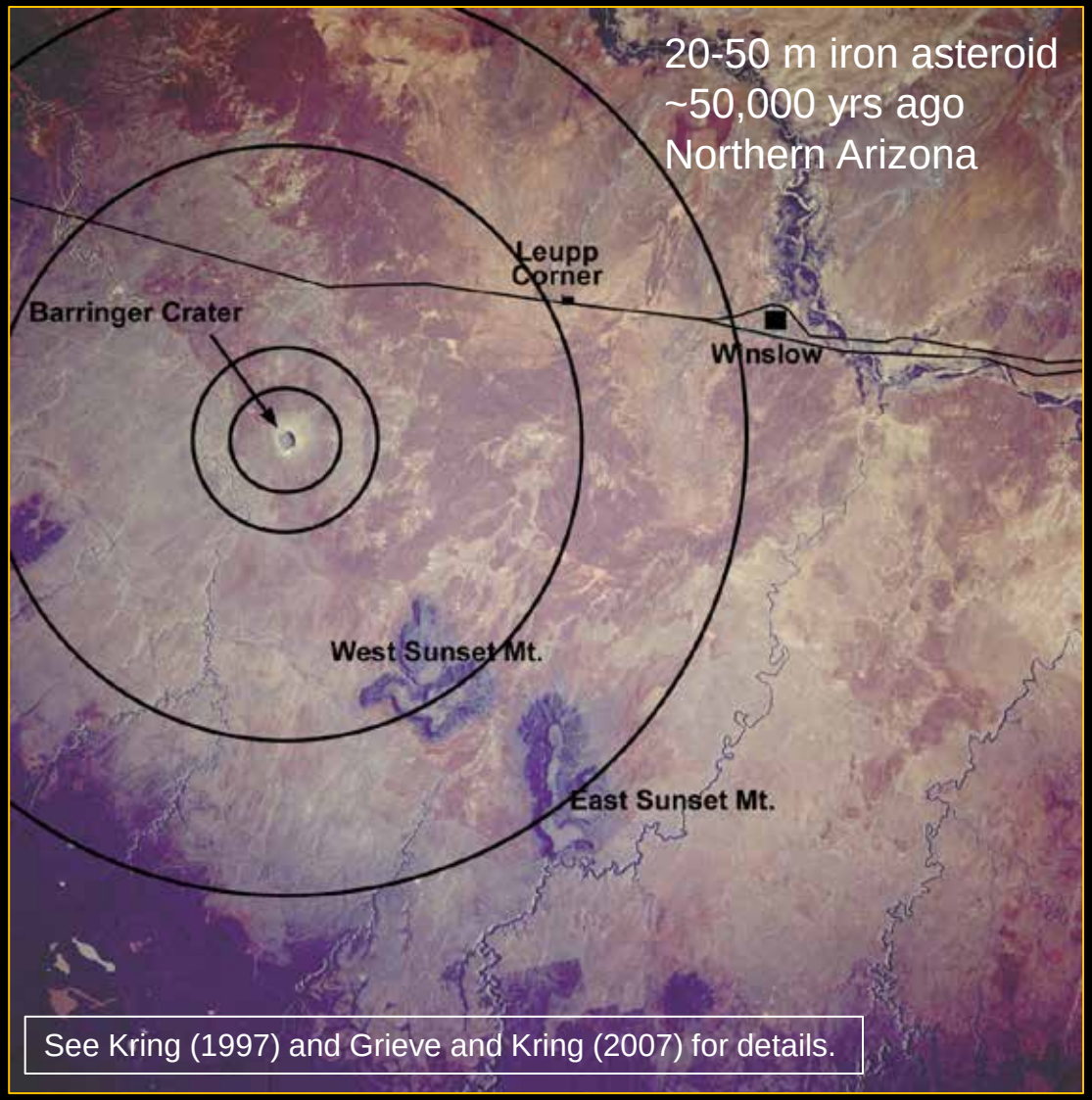
Modified after Kring (1997)

Relative damage zones

The effects of the Odessa impact, while locally dramatic, were far more limited than those produced around the Barringer impact crater.

The effects of Odessa (innermost yellow circle) did not extend to a distance any larger than the continuous ejecta blanket of Barringer crater (about 2 km), while the effects of the Barringer imapct extended tens of kilometers (larger red, yellow, and blue circles).

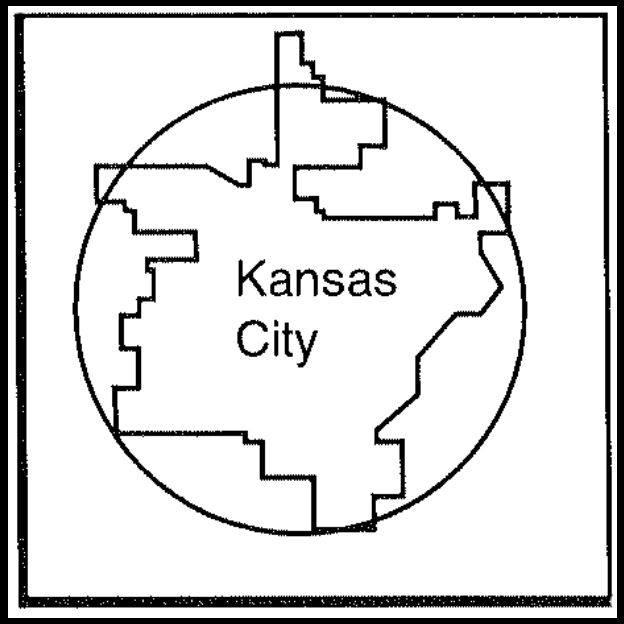
CASE STUDY OF AN IMPACT AIR BLAST – BARRINGER (METEOR) CRATER



See Kring (1997) and Grieve and Kring (2007) for details.

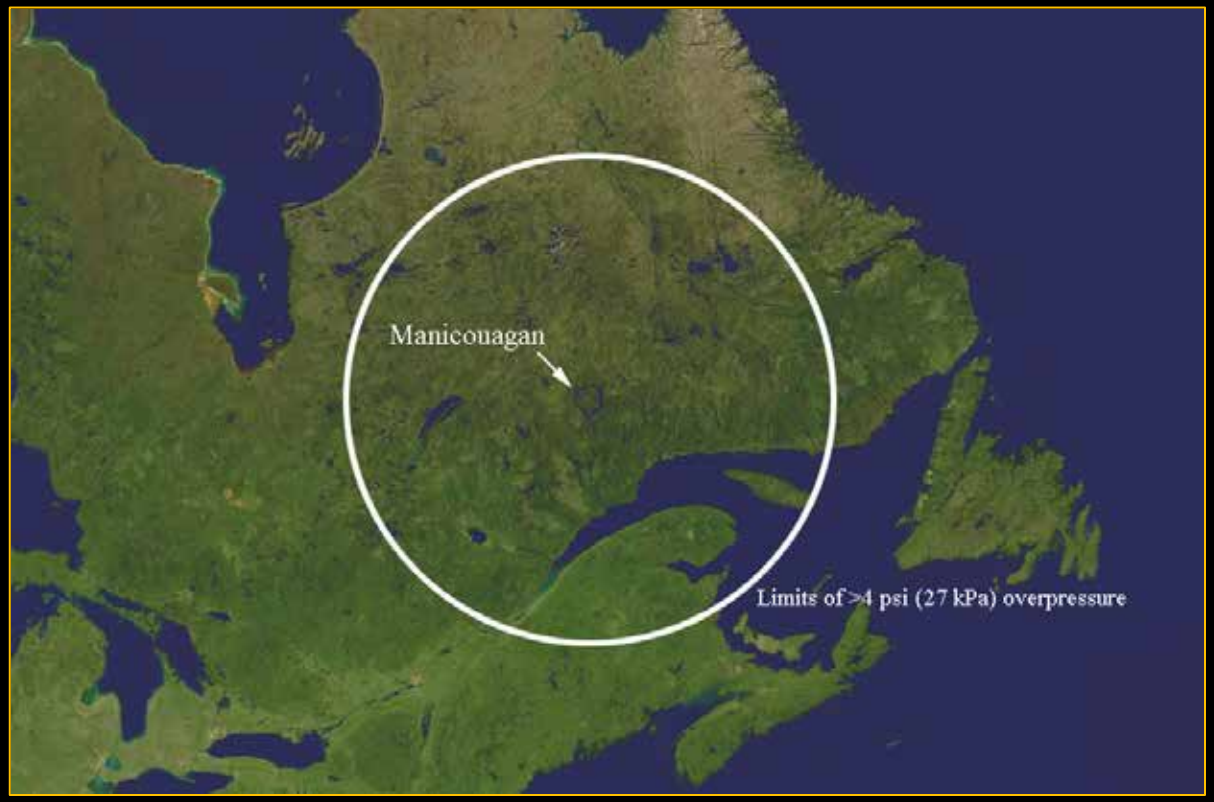
Small cratering events

Such an event today could decimate the population of an urban area equivalent to the size of Kansas City, U.S.A. (population 425,000).



40 km circle corresponding to severe to moderate damage.

CASE STUDY OF AN IMPACT AIR BLAST – MANICOUAGAN



Grieve and Kring (2007)

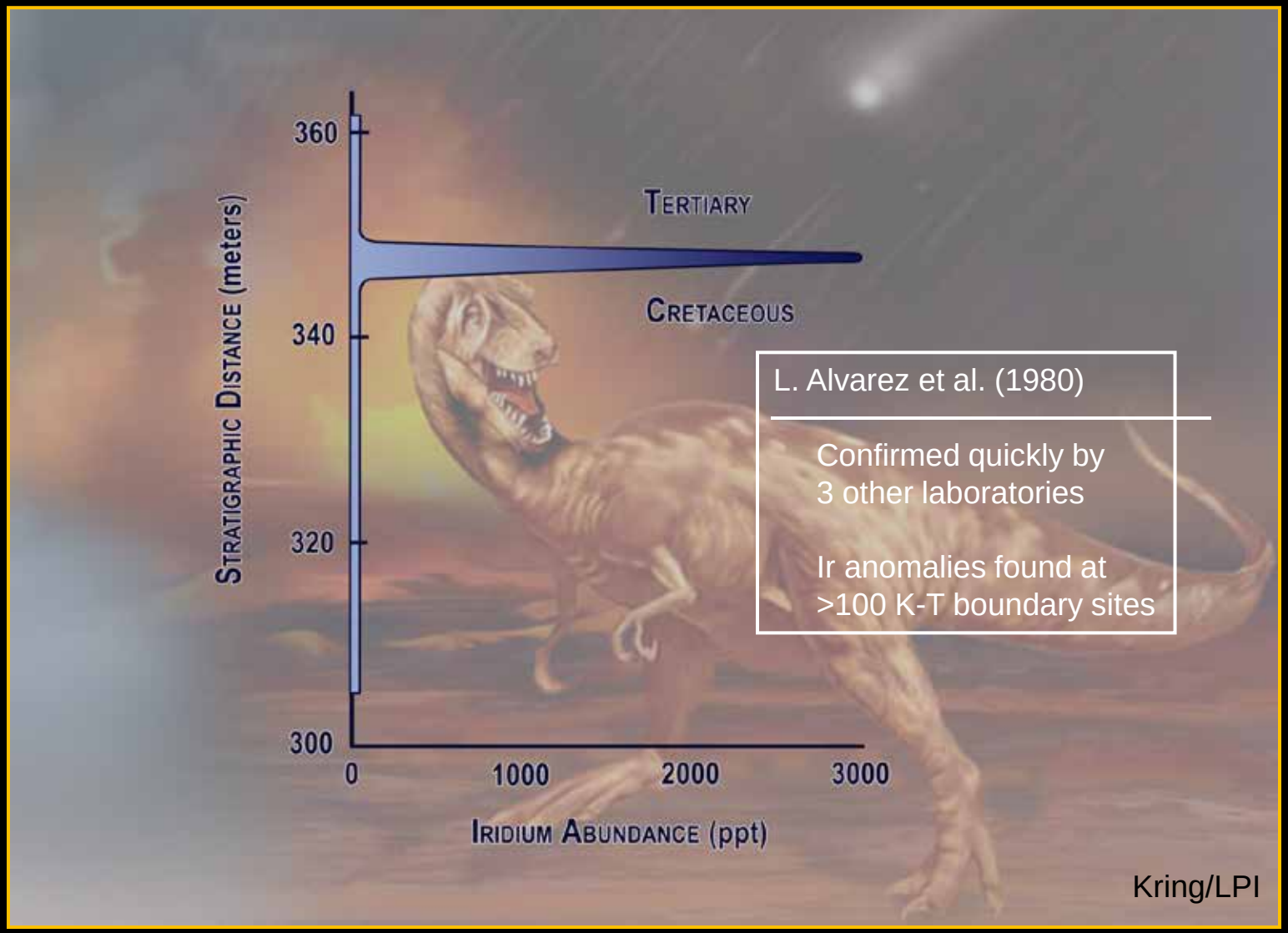
Manicouagan

Larger impact cratering events will produce air blasts that affect a larger area.

Manicouagan is a crater with a diameter of ~100 km.

That impact air blast affected a large fraction of Canada (over a diameter of ~1,100 km).

CASE STUDY OF AN IMPACT AIR BLAST – CHICXULUB CRATER



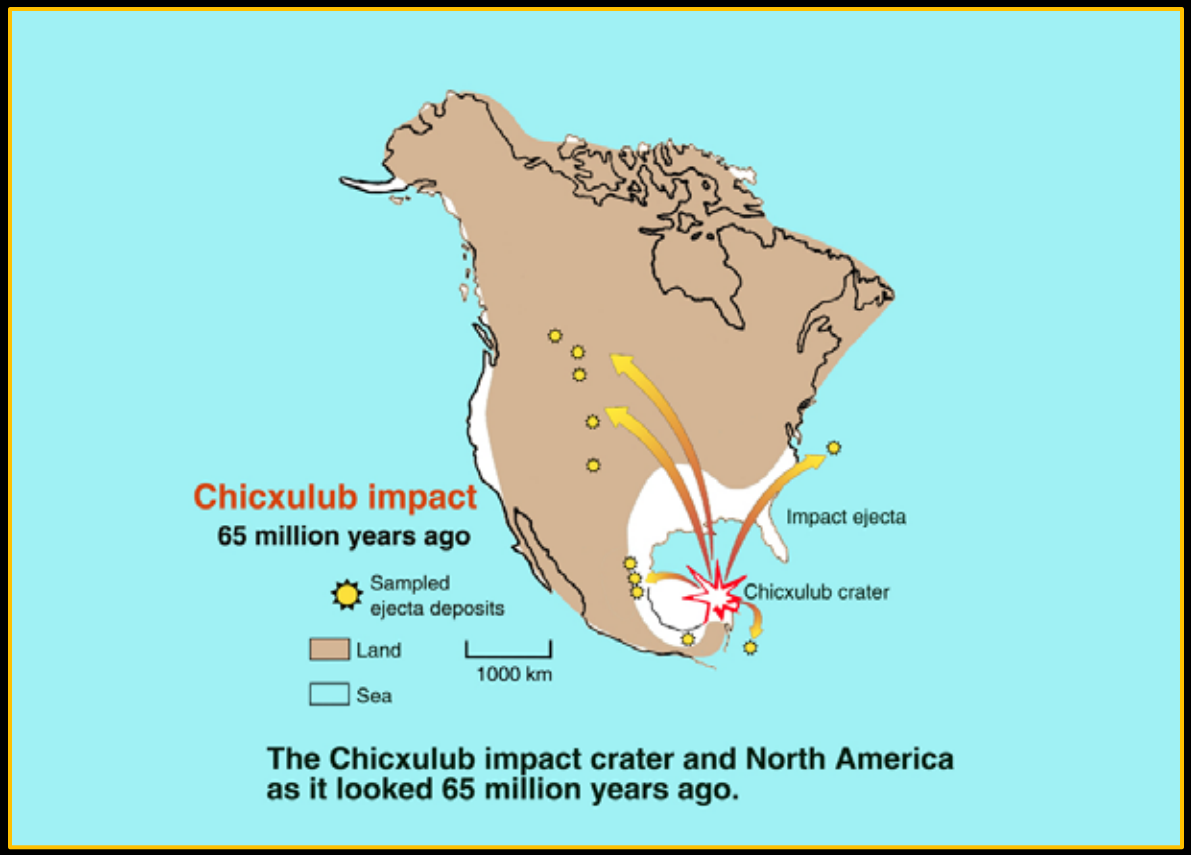
L. Alvarez et al. (1980)

Confirmed quickly by 3 other laboratories

Ir anomalies found at >100 K-T boundary sites

Kring/LPI

CASE STUDY OF AN IMPACT AIR BLAST – CHICXULUB CRATER



The Chicxulub impact crater and North America as it looked 65 million years ago.

Kring et al. (1991); Hildebrand et al. (1991)

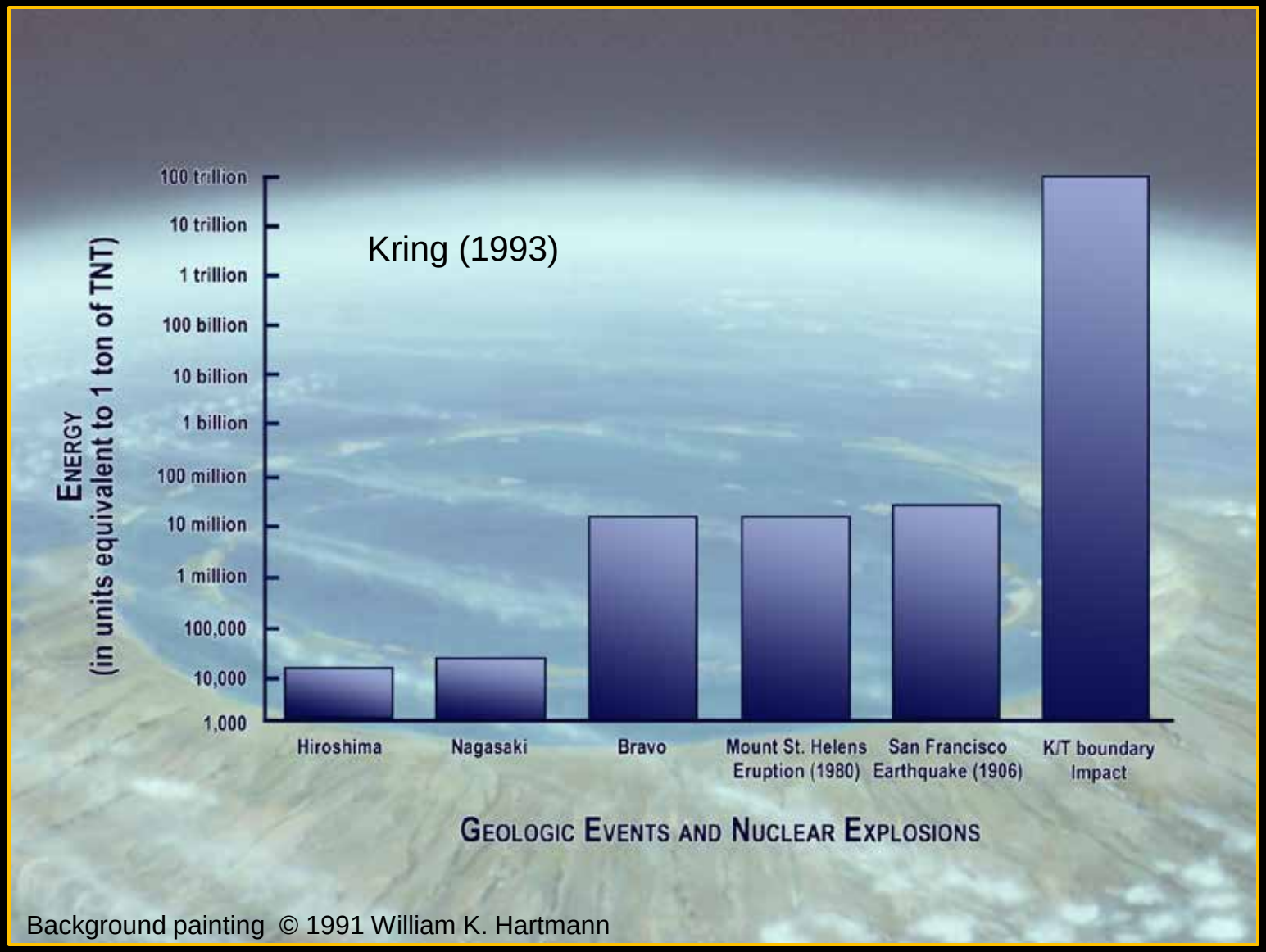
Dinosaur-killing event

At the extremely large end of the spectrum is the Chicxulub impact event that caused a mass extinction 65 million years ago.

This event produced a crater about 180 km in diameter.

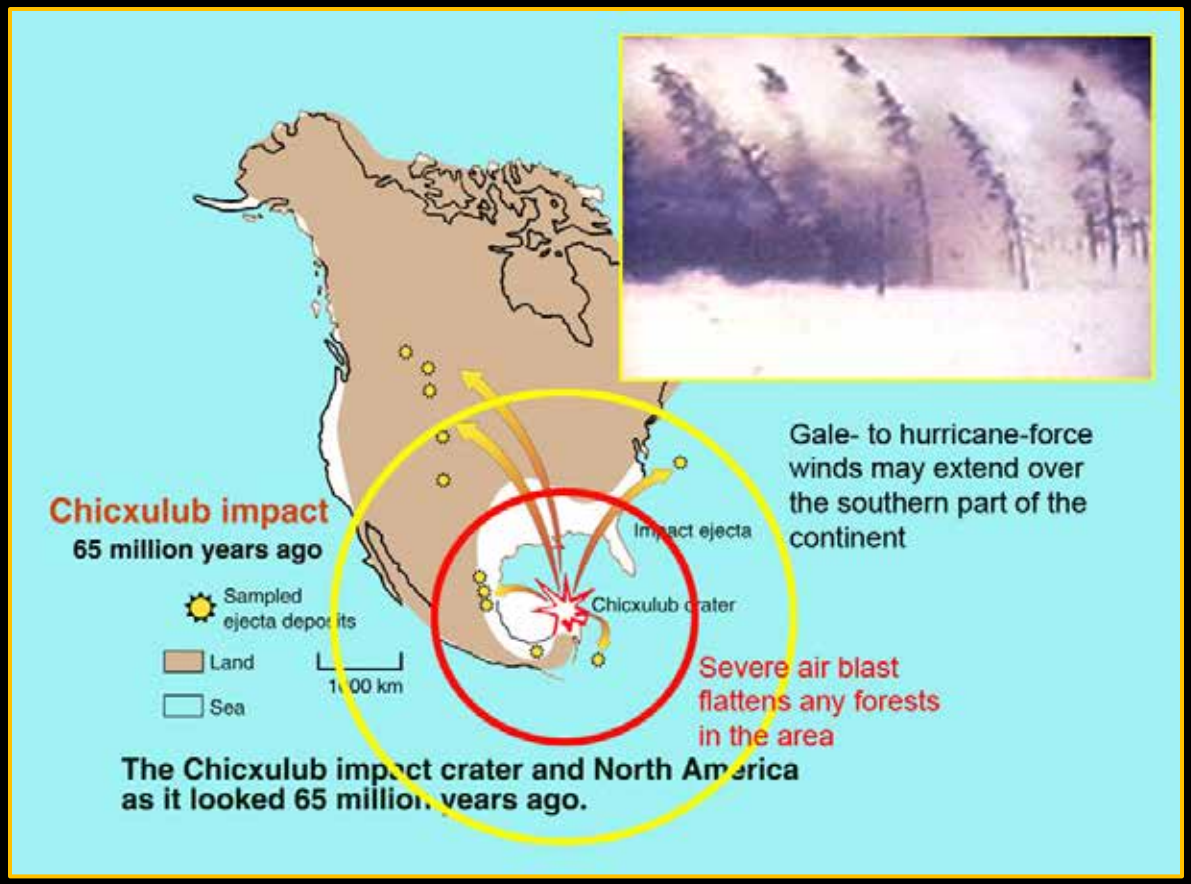
The NEO was likely a carbonaceous chondritic asteroid, although a carbonaceous-bearing comet cannot yet be ruled out.

CASE STUDY OF AN IMPACT AIR BLAST – CHICXULUB CRATER



Background painting © 1991 William K. Hartmann

CASE STUDY OF AN IMPACT AIR BLAST – CHICXULUB CRATER



See Emiliani et al. (1981) and Kring (2007) for details.

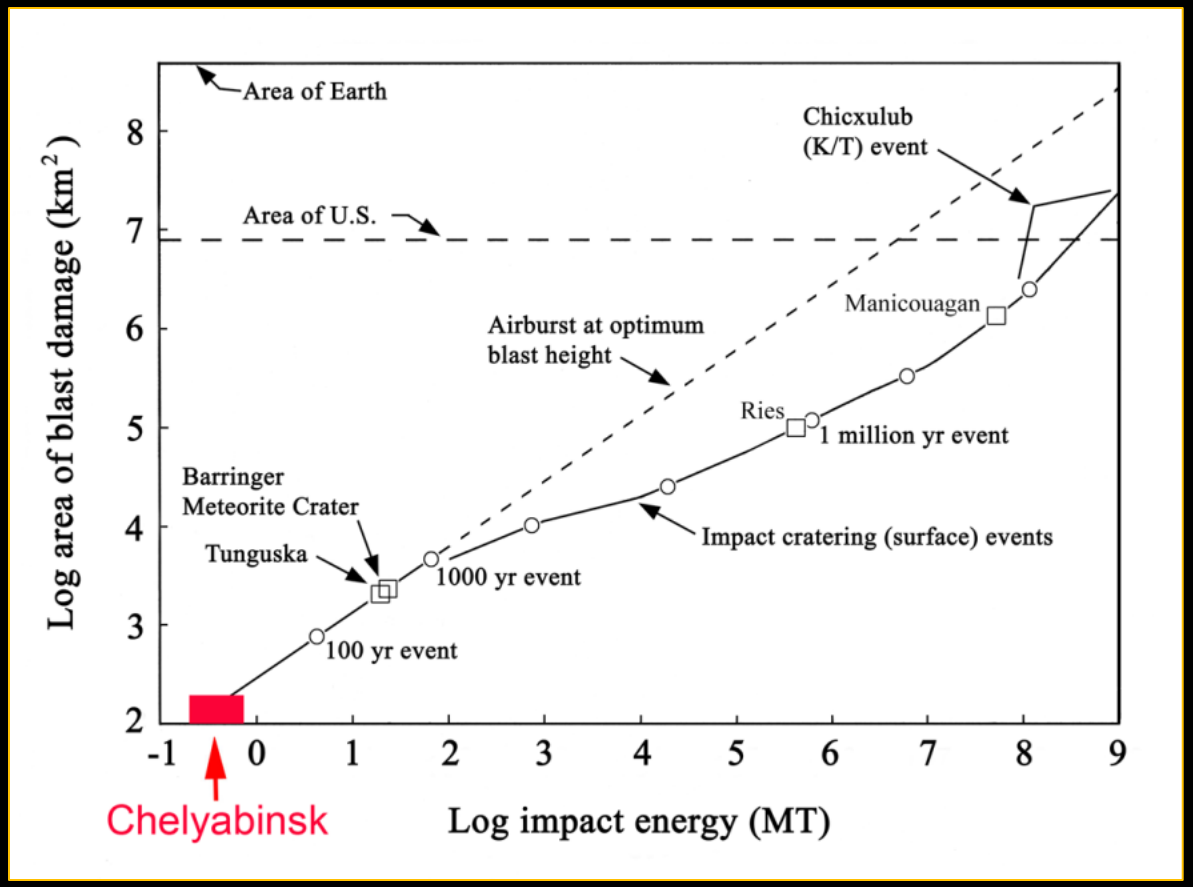
Dinosaur-killing event

At the extremely large end of the spectrum is the Chicxulub impact event that caused a mass extinction 65 million years ago.

The air blast produced by that impact event affected a large fraction of North America.

The airblast is only one of many environmental effects produced by this size of impact event.

IMPACT AIR BLASTS OF DIFFERENT SIZES



Modified after Figure 1.5 of Grieve and Kring (2007). Please see that paper or PPTx notes (below) for a description of the uncertainties associated with the data plotted in the diagram

Impact air blasts

The Chelyabinsk event is at the extreme (small) end of the types of events that produce air blasts.

Less frequent, larger events can affect larger areas.

As the world's population grows and occupies a larger fraction of the Earth's surface, events like Chelyabinsk will potentially affect more people.

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER

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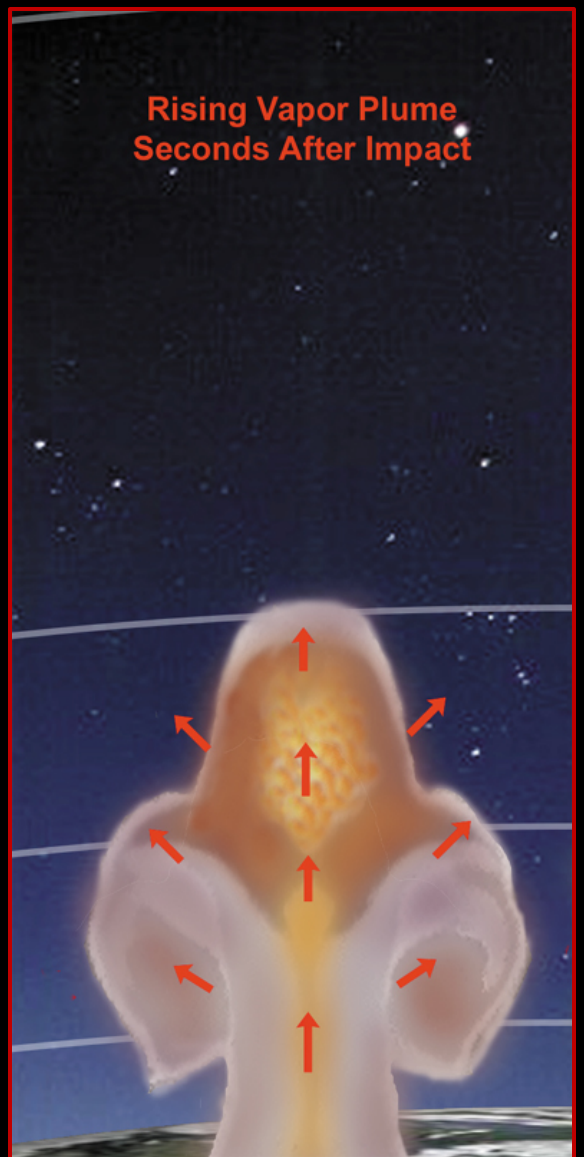
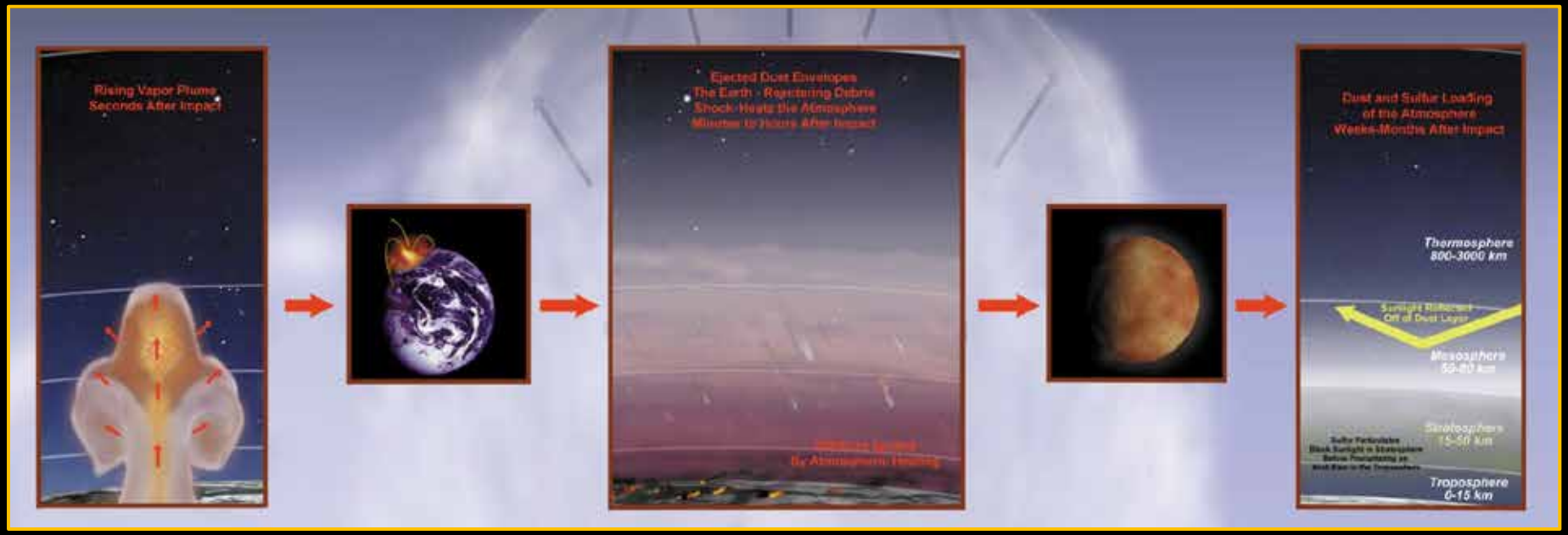


To produce a global mass extinction event, however, other processes are required.

Those processes are linked to the production of a vapor-rich plume of impact ejecta

Kring et al. (2002)

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER

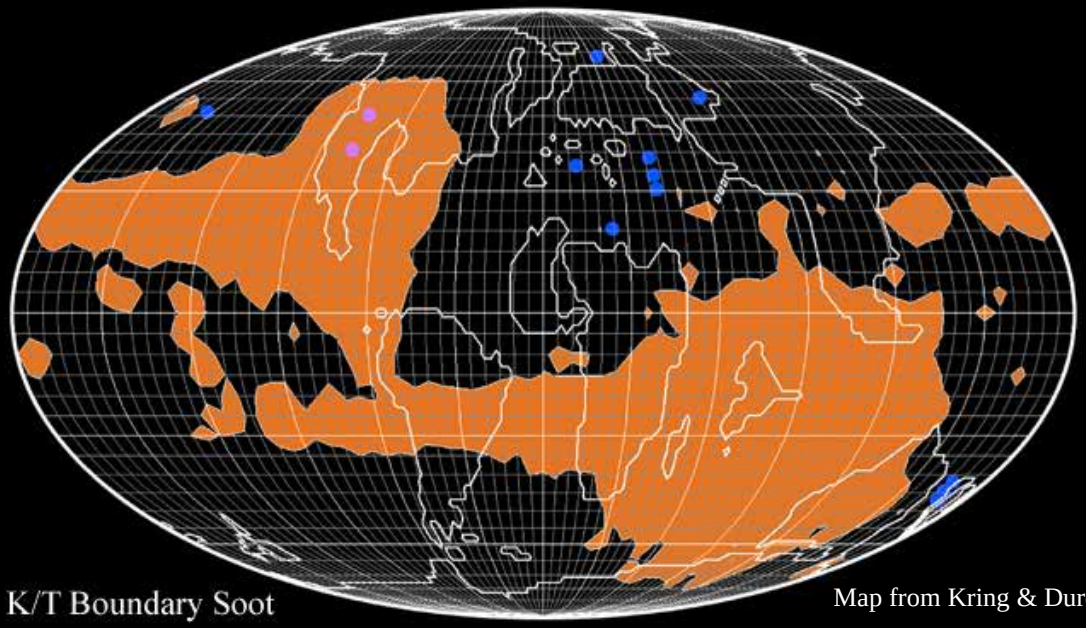


Kring et al. (2002)

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER

- Atmospheric heating may have been sufficient to spontaneously ignite fires (e.g., orange-colored regions that cover land

- Soot produced from burning vegetation is found in K/T boundary sediments



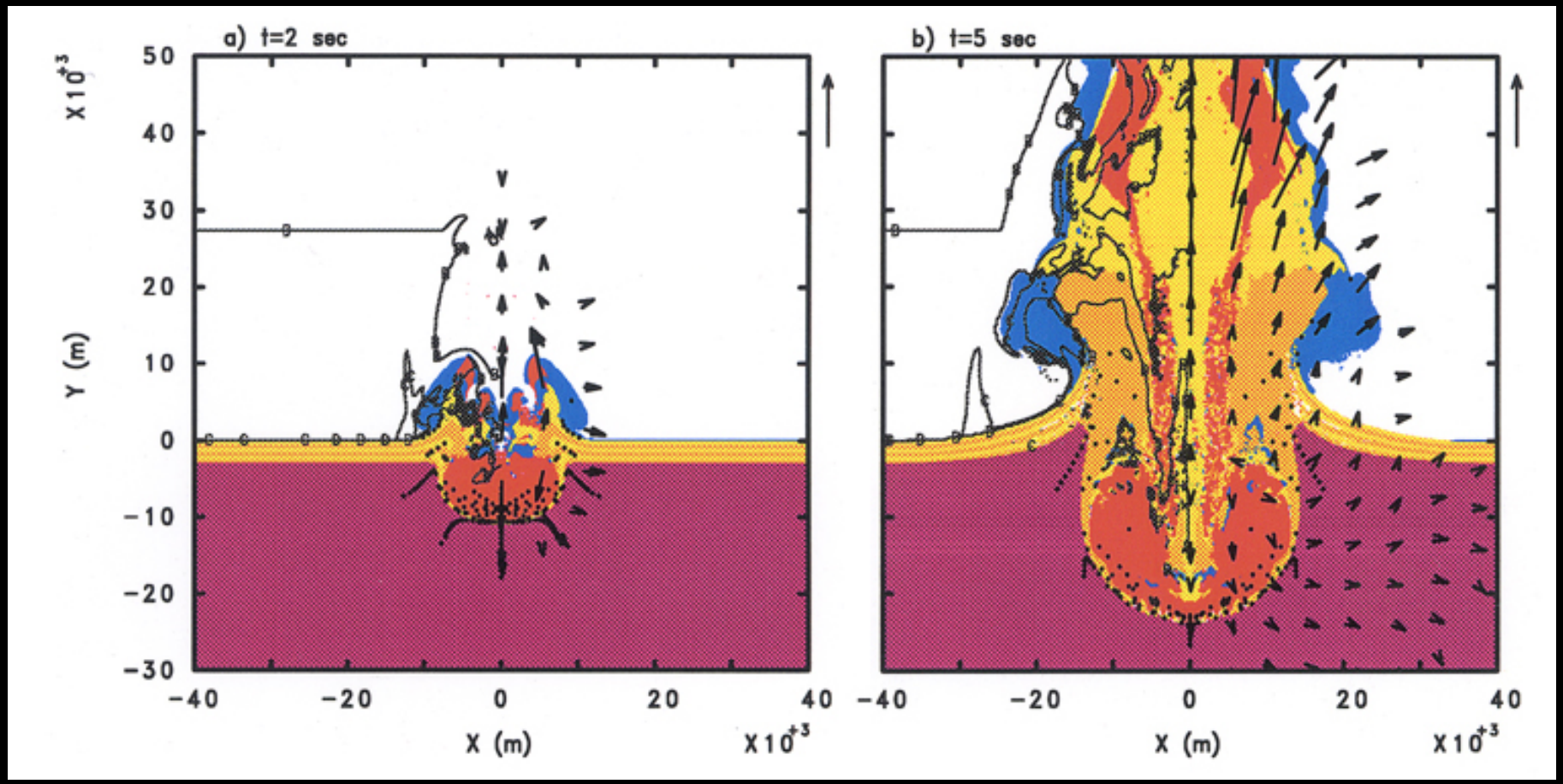
Map from Kring & Durda (2002)

- A biologic signature of wildfires, a fern spore spike, is also found immediately after the impact event

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER

Limestone	Anhydrite
$CaCO_3$	$CaSO_4$
↓	↓
$CaO + CO_2$	$CaO + SO_3$
Generates greenhouse-warming gas	Generates sulphate aerosols & sulfuric acid rain

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER



Pierazzo, Kring, and Melosh (1998)

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER

	Mass Degassed (GT)	Mass Added to Atmosphere (GT)	Enrichment Factor*
CO_2	830 - 910	575 - 625	< 1.2
S	110 - 140	55 - 70	$5.5\text{-}7 \times 10^5$
H_2O	385 - 415	385 - 415	130 - 140

10 km diameter projectile, 180 km diameter crater, 10% porosity

* In the case of CO_2, the value is relative to the late-Cretaceous atmosphere; in the case of S and H_2O, the values are relative to the modern stratosphere.

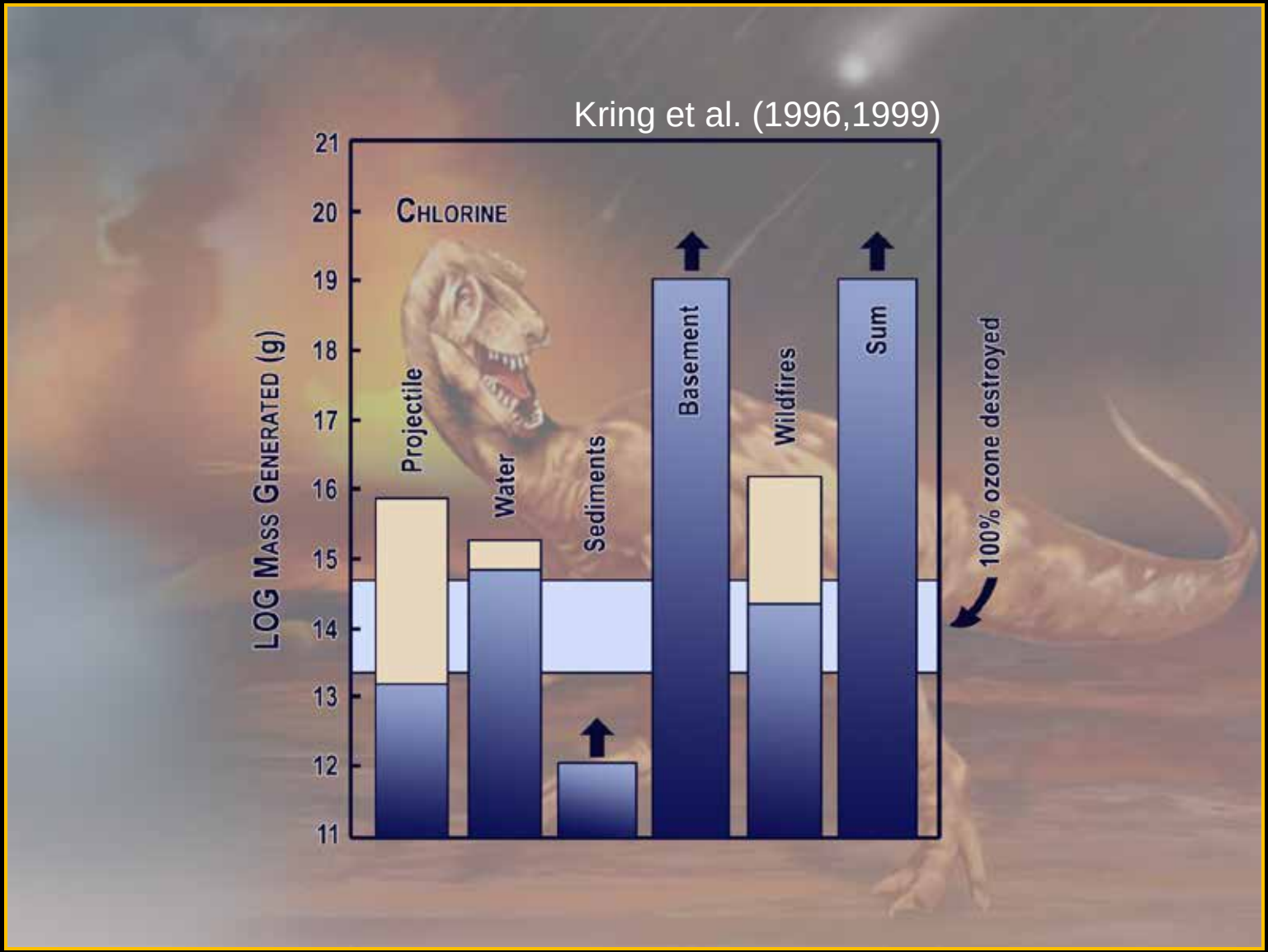
(An even larger amount of CO_2 (plus CO and CH_4) was produced by the impact-generated wildfires.)

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER

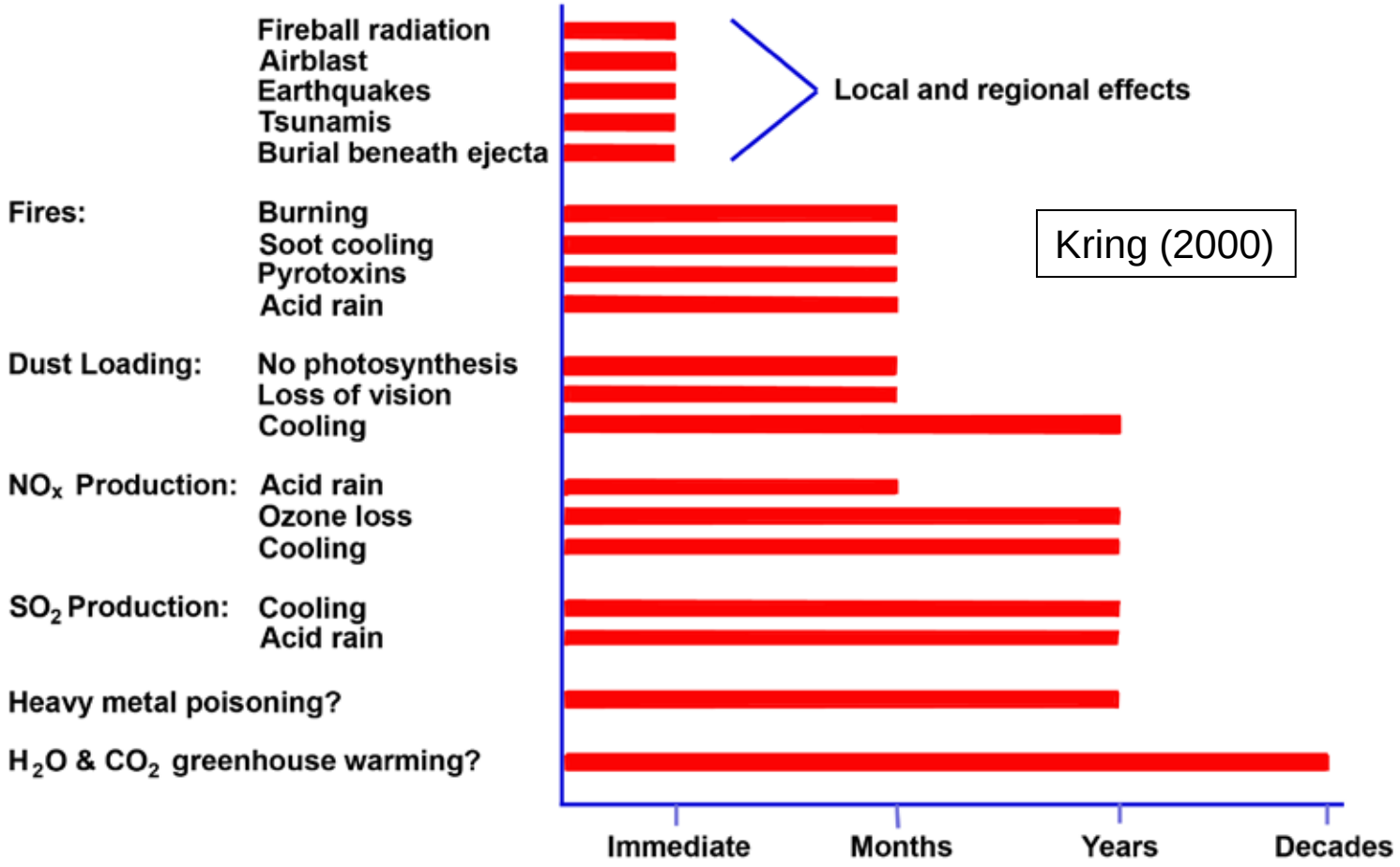
Impact heating alters the nitrogen chemistry of the atmosphere, leading to nitric acid rain

Shock & radiative heating produces 3×10^{10} to 9×10^{12} metric tons of NO (e.g., work by Lewis, Prinn, Fegley, & Zahnle in several papers 1983-1990).

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER

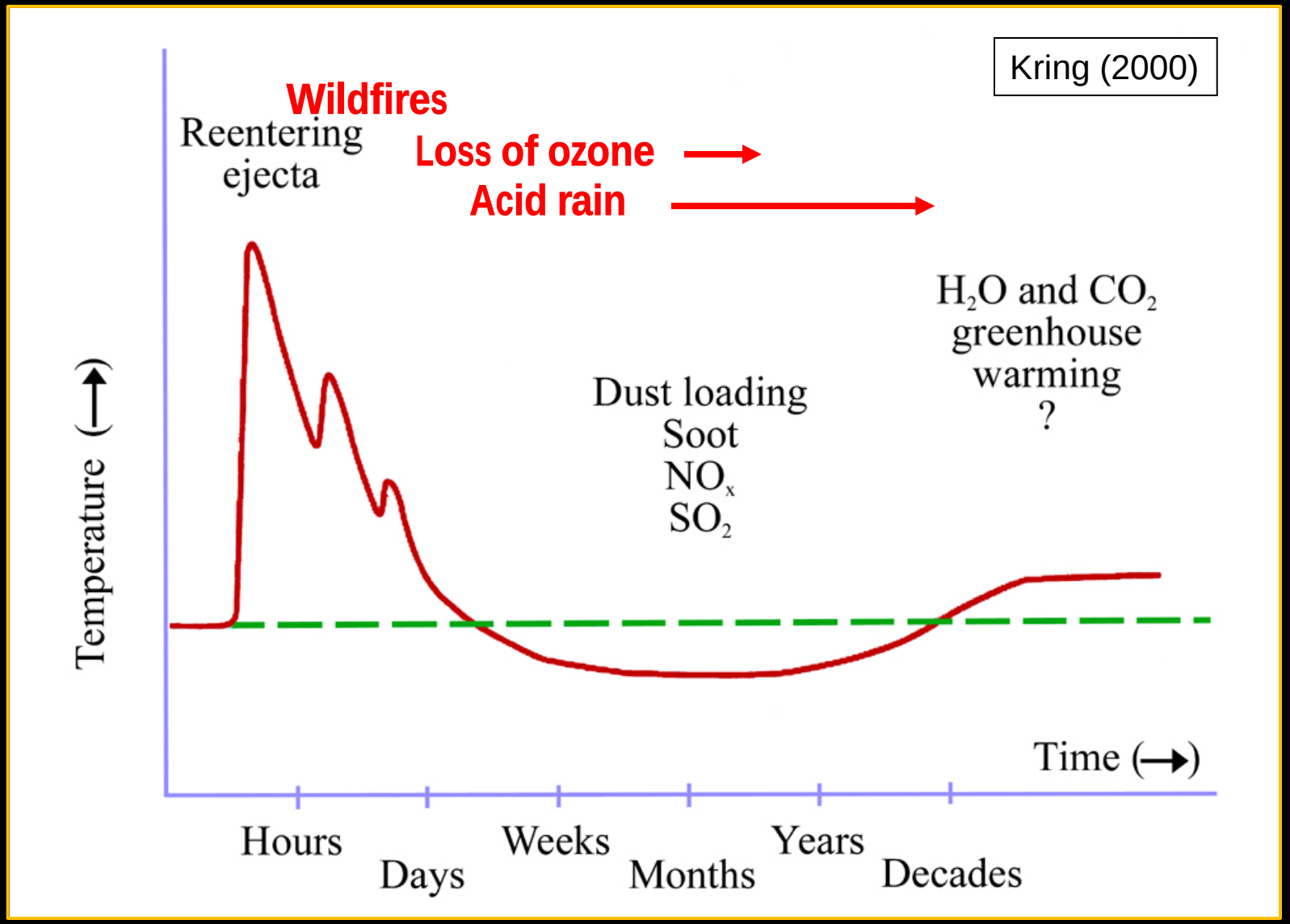


CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER



Kring (2000)

CASE STUDY OF LARGE NEA IMPACTS – CHICXULUB CRATER



SUMMARY

- Small stony NEA strike far more often than small iron NEA
- Small stony NEA are more likely to catastrophically fragment in the atmosphere &, if sufficiently large, will produce a shock wave and air blast that reaches the ground (e.g., Tunguska, Chelyabinsk)
- In contrast, small iron NEA of the same size may reach the ground largely intact; they may begin to fragment, producing multiple small craters (e.g., Odessa), or produce a single large crater (e.g., Barringer).
- In these relatively small cratering events, the dominant environmental effects are a fireball, shock wave, air blast, and local burial beneath ejecta.
- Larger NEA, such as the one that produced the Chicxulub crater, create those same effects, but also have the capability of distributing environmentally devastating debris globally.
- The smaller events, while less damaging, occur more frequently.
- A Meteor Crater-size impact event has the capacity to destroy a modern city.

Thank you.

Questions?

For more details of the Chelyabinsk Air Burst, please see the hour-long video lecture at

http://www.lpi.usra.edu/education/lectures/

Title
The 2013 Chelyabinsk Air Burst and the Hazards of Near-Earth Asteroid Impacts

Presented by
David A. Kring