13. Environmental Effects of the Impact ❖❖❖

The relationship between the Chicxulub impact event and a mass extinction at the Cretaceous-Tertiary boundary has promoted an assessment of the environmental effects of impacts of all sizes. Such studies have two components. First, they must reconstruct the environment at the time of impact. Second, they must determine the effects of the impact on that environment and the plants and animals within it. An initial attempt to resolve those issues at Barringer Crater appeared two decades ago (Kring, 1997) and will be summarized here. As discussed at the time, there were numerous uncertainties in the baseline data being used, so a discussion of possible permutations will also appear below.

Any age for the crater within 20,000 yrs of 50 ka places the impact event within the Wisconsin interstadial, which is a relatively warm interval during the Wisconsin period of glaciation. The topography was similar to that seen today. The average slope was ~0.5° to the northeast. Moenkopi ridges had an average relief of ~5 to 10 m and the maximum topographic high was no more than ~20 m. Drainage systems may have been more active than they are today, because the climate was wetter during the Wisconsin period. Gilbert (1896) even suggested the impact hit a small drainage system. Most of the volcanic features in the region were present, with the possible exception of few cinder cones with age comparable to or younger than that of the crater.

Currently, the vegetation around the crater is dominated by a grassland (Fig. 13.1). At lower elevations to the east, the grassland is replaced by a sagebrush ecosystem. At higher elevations to the west, the grassland is replaced sequentially by a woodland and pine forest. The woodland is dominated by juniper and pinyon, small patches of which can also be found on the south crater rim. The understory of the woodland is composed of grasses and shrubs. The pine forest is dominated by Ponderosa Pine at lower elevations and a mixture of Douglas-fir, White-fir, Limber Pine, and Aspen at higher elevations. Spruce-bearing conifer forests and alpine tundra occur at the highest elevations in the San Francisco Peaks, ~60 to 70 km northwest of the crater.

At the time of impact, these vegetation zones were shifted to lower elevations, because of climatic conditions during the interstadial. Pollen deposited in lake sediments throughout the region suggested woodlands may have been established near the crater and possibly at the impact site (Kring, 1997). Efforts to improve this floral reconstruction continue and have benefitted greatly from the expertise of Owen Davis, who is one of the leading palynologists in the American southwest. In a preliminary study (Davis and Kring, 2002), lake sediment deposited on top of the impact breccia lens was recovered ~30 m beneath the crater floor. Davis' pollen analysis confirms the climate favored the types of forests now restricted to the highlands of the Flagstaff area. However, the concentration and diversity of the pollen is low and dominated by wind-dispersed pollen types, suggesting long-distance transport and locally sparse vegetation at the crater. The impact may have occurred in a sagebrush community, bordered by a narrow woodland that transitioned to pine and spruce forests over short distances (Fig. 13.2).

The surrounding sagebrush steppe, woodland, and forest terrains were populated with mammoths, mastodons, large ground sloths, tapirs, bison, camels, and horses (Kring, 1997). Mammoths grazed on sagebrush and related vegetation, so they may have been in the immediate vicinity of the impact. They also migrated into nearby spruce forests. Mastodons preferred to browse in spruce forests, pine forests, and woodlands. Large ground sloths preferred to graze and browse in sagebrush and open woodlands, along with bison and camels.

In this type of environment, the most destructive components of the impact event were ejected debris, a fireball, a radiating shock wave, and a closely related air blast. These effects were confined to the region. A small amount of seismic energy was generated and small amounts of climatically-active gases (*e.g.*, CO, CO_2, SO_2 and/or SO_3, H_2O, Cl, and Br) were released, but of little consequence.

The magnitude and radial extent of a radiating shock wave and air blast depends on the energy of the impact event. (It also depends on the trajectory, but that issue will be discussed separately.) At the time of Kring's initial study, Roddy and Shoemaker (1995) estimated the impact energy was equivalent to 20 to 40 MT of TNT. As discussed in Chapter 10, more recent calculations suggest lower energies. For purposes of discussion on the field trip, some of the effects are illustrated (Fig. 13.3) for a 20 MT blast, with the caveat that smaller radii may apply to the effects if lower impact energies are appropriate.

We do not yet know if the impact occurred during the day or night. Nonetheless, a relatively pastoral scene was disrupted when an iron asteroid came hurtling through the atmosphere. The meteor would have split the sky along a bright path of light before slamming into the ground. Plants and animals at ground zero were vaporized, while most of the asteroid and some of the underlying bedrock were obliterated. Bedrock below and around the vapor-melt zone was then ejected and overturned, burying the topography and any plants and animals not already swept away by an air blast.

The collision generated a shock wave, as described previously in Chapter 4. In addition to radiating into target bedrock and the asteroid, a shock wave radiated across the landscape. This created dramatic overpressures. It also generated an air blast. These winds were in excess of 1000 km/hr in the vicinity of the impact event (Fig. 13.3) and decreased with distance. The winds severely damaged trees in any forested area within a diameter of 32 km. Grass, small shrubs, and soil were probably stripped from the area near the crater by these high velocity winds. A small amount of material can potentially have been trapped beneath the overturned ejecta, because roots in soil were preserved in a similar position around the Sedan nuclear explosion crater (Carlson and Roberts, 1963). I have not yet found, however, any material sandwiched in Moenkopi hinges along the crater wall or in drill samples that penetrated that contact beneath the ejecta blanket.

Shock overpressure and wind velocity diminished with distance, falling from 2200 km/hr at a radial distance of 3 km to 800 km/hr at a radial distance of 6 km, but remaining fairly large for distances approaching 30 km. Throughout a circular region up to 32 km in diameter, the large mammals described above would have been killed or wounded by the pressure pulse and air blast. Some of the injuries would have been directly caused by the pressure pulse. For example, it would have caused rapid pressure oscillations in air-containing organs and damaged areas between tissues of different densities (*e.g.*, near joints). This would have generated hemorrhaging and edema in the lungs that caused suffocation, air emboli that may have obstructed blood vessels in the heart and brain, and fibrin emboli in the blood that may have damaged the brain and other organs. In addition to these direct blast injuries, animals would have been injured when the blast wave hit them, accelerated their bodies to velocities on the order of a few to tens of kilometers per hour, and then slammed them back onto the ground or they collided with other objects. The air blast also picked up broken branches, rocks, and other types of missiles that created a fusillade of debris that impaled, lacerated, or otherwise traumatized animals.

These are the effects of the impact and crater-excavating blast. Additional damage was created by the ballistic shock wave. Because we do not yet know the trajectory of the object (Chapter 10), these effects are more difficult to quantify. However, it is likely that a ballistic shock expanded the region affected by many of the processes described above.

As far as we can tell, the northern Arizona impact was not witnessed by or involved any humans in the region. (It is more likely that the Gold Basin event was witnessed, because it occurred ~15,000 yrs ago.) If a similar size impact were to occur over a modern city, however, that city would largely be destroyed. As an example, the effects above have been mapped to Kansas City (Kring, 1997).

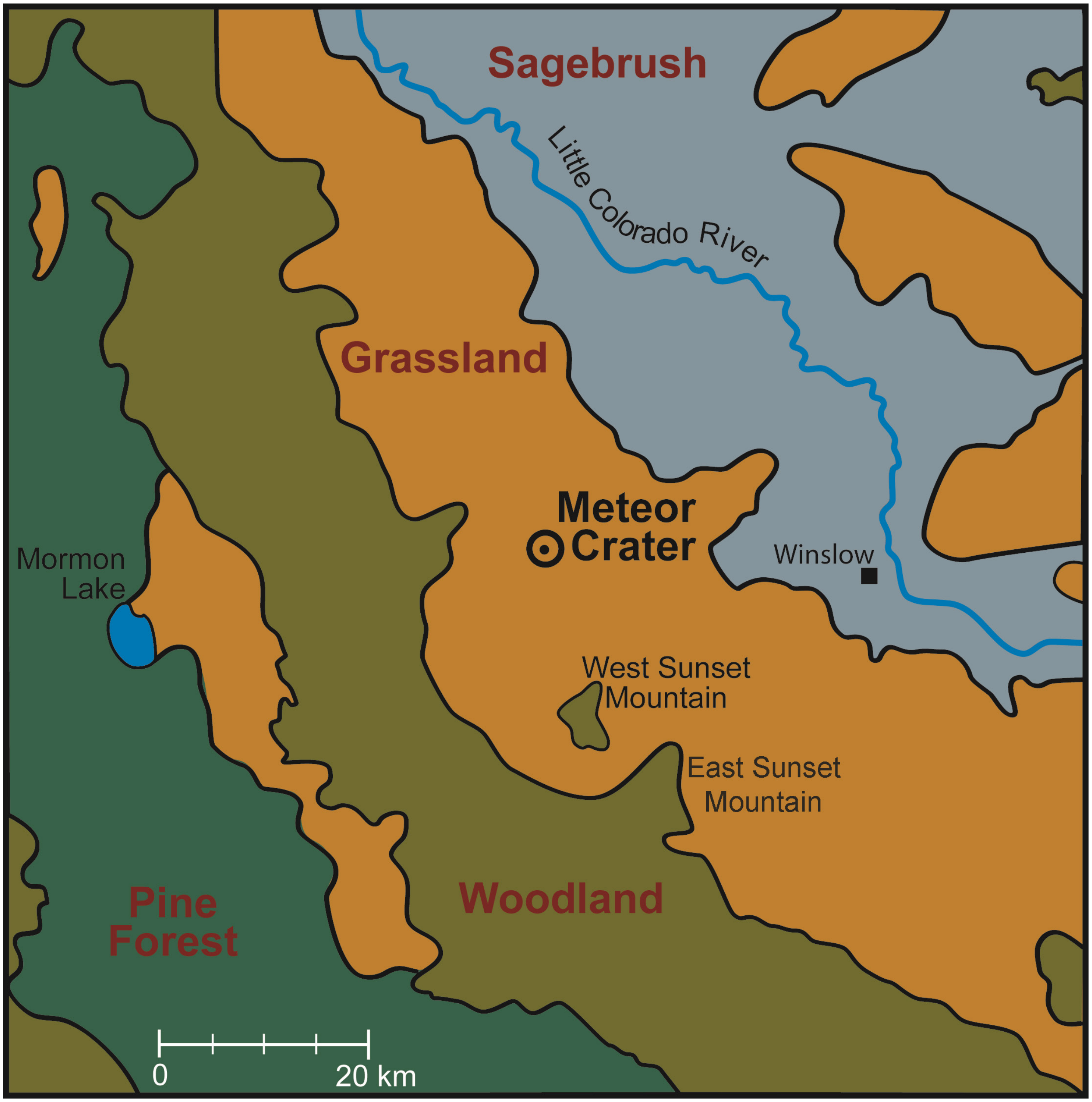

Fig. 13.1. Map showing the distribution of biotic communities in the area around Meteor Crater today. The zones of sagebrush, grassland, woodland, and pine forest are extracted from a map of southwestern biotic communities by Brown and Lowe (1980). This is a slightly simplified and colorized version of a map that appeared in Kring (1997), which should be consulted for additional details about the vegetation in the immediate vicinity of the crater.

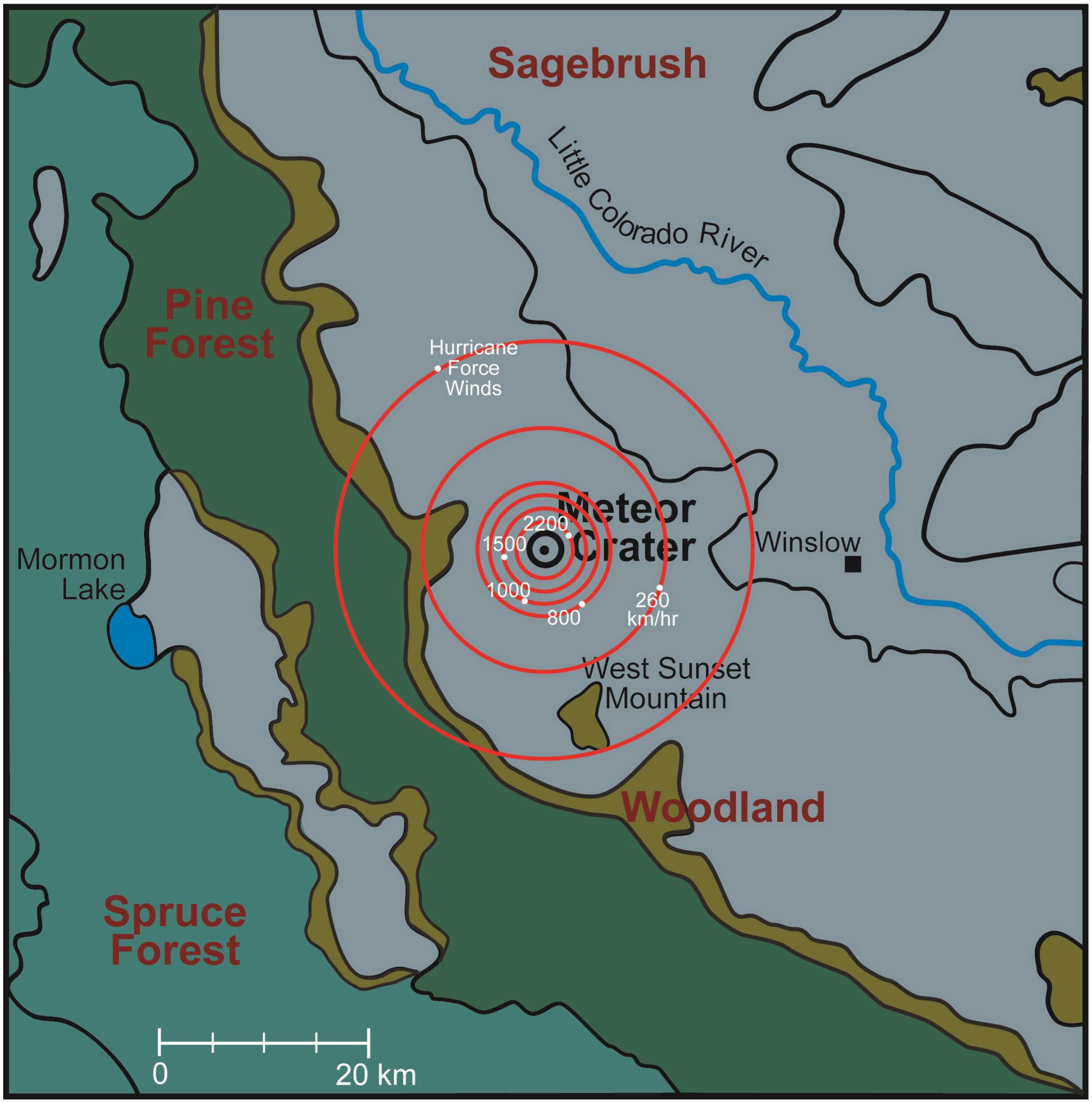

Fig. 13.2. A preliminary palynological study of sediments deposited immediately on top of the mixed debris unit on the floor of the crater has been used to reconstruct the vegetation zones that may have existed at the time of impact ~50,000 years ago (Davis and Kring, 2002). The climate at the time of impact favored the types of forests that are now restricted to the highlands of the Flagstaff area (Kring, 1997). The concentration and diversity of the pollen in the crater sediment is low and dominated by wind-dispersed pollen types, suggesting long-distance transport and locally sparse vegetation at the crater (Owen Davis, personal communication). Thus, upland vegetation near the crater was probably a conifer groveland, with stands of pine, spruce, and fir scattered along a sagebrush steppe. In contrast to a previous reconstruction (Kring, 1997), the new data suggest forests were a few kilometers west of the crater, rather than in the immediate vicinity of the crater at the time of impact. As the new study proceeds, additional samples will be analyzed to further refine our reconstruction of environmental conditions at the time of impact. Also indicated on the map are the wind velocities generated by the impact event, assuming an impact energy of 20 MT. Wind velocities at radial distances of 3, 4, 5, 6, and 12 kilometers were 2200, 1500, 1000, 800, and 260 km/hr (Kring, 1997). Category 3 hurricane-force winds existed at a radial distance of 20 km (outermost red circle). Although not shown, hurricane-force winds extended to a radial distance of 30 km.

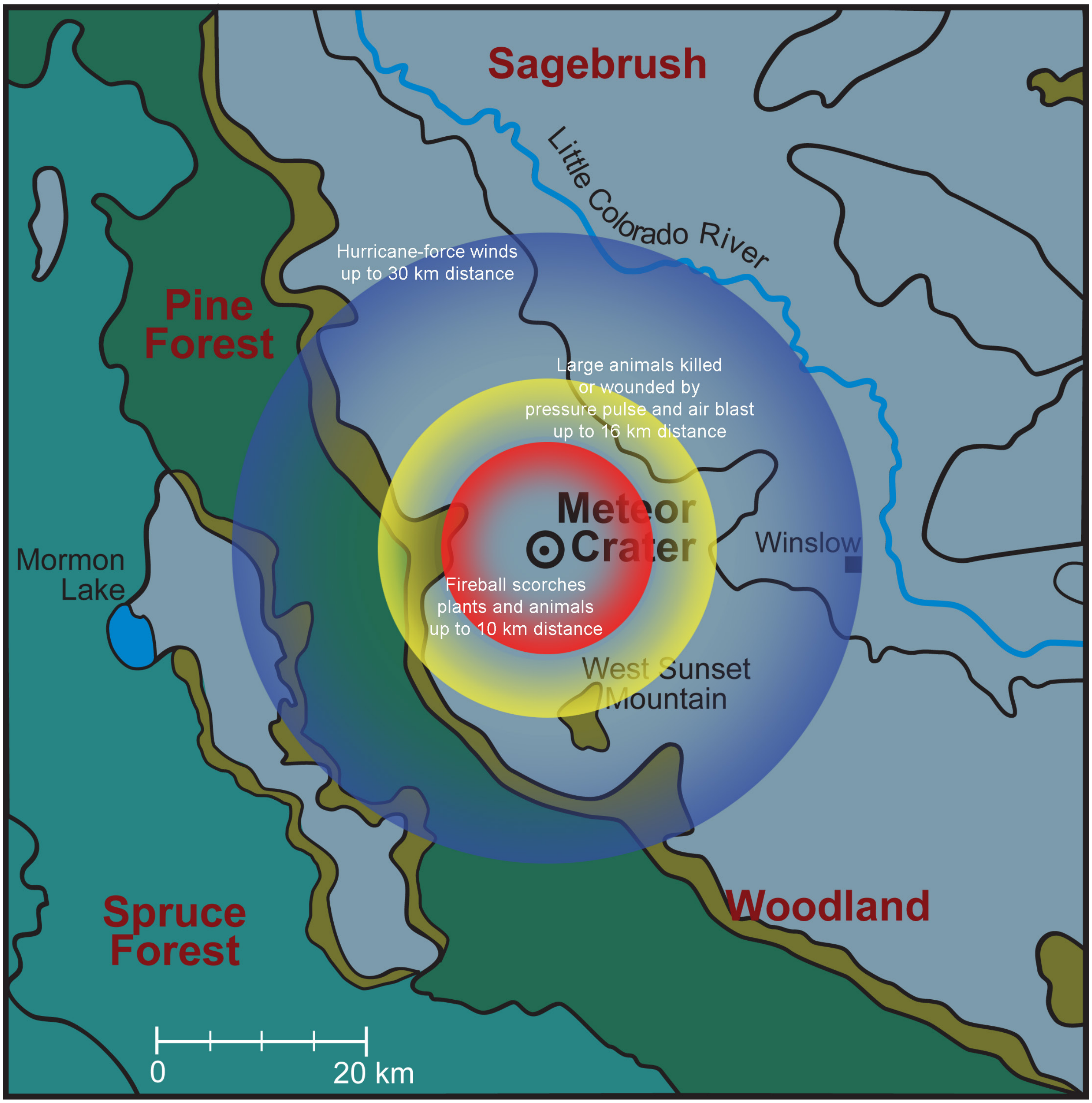

Fig. 13.3. The surrounding sagebrush, woodland, and forest terrains were populated with mammoths, mastodons, large ground sloths, tapirs, bison, camels, and horses. Mammoths grazed on sagebrush and related vegetation, so they may have been in the immediate vicinity of the impact. They also occasionally migrated into spruce forests. Mastodons preferred to browse in spruce forests, pine forests, and woodlands. Large ground sloths preferred to graze and browse in sagebrush and open woodland communities. Similarly, bison and camels migrated through both sagebrush and open woodland communities. Presumably horses did the same, but their distribution 50,000 years ago is less well-known. Shock pressures, wind velocities, and heating were greatest within a few kilometers of the impact. The fireball scorched plants and animals out to a maximum distance of 10 km (red circle). Large animals were killed or wounded by the pressure pulse and air blast out to a distance of 16 km (yellow circle). The air blast decelerated with distance from the crater. The maximum limit of hurricane force winds was 30 km (blue circle). These radial distances assume a 20 MT impact event.