Intrusive igneous rocks are those that form from the solidification of a magma below the earth's surface. The size and shape of an intrusion, or body of solidified magma, is dictated by numerous factors. Geologists give different names to igneous intrusions that are based on the depth of emplacement, the specific orientational relationship to the surrounding host rocks, and the shape and size of the intrusion. Such names as dike, sill, volcanic plug, and many others are used to describe these features. As seen below, diatremes are a special type of igneous intrusion.

When the central conduit or vent that feeds magma to a volcano becomes sealed by the solidification of magma within it, the resulting cylindrical column of intrusive rock is called a volcanic plug. If the plug forms within rocks that are less resistant to weathering than the plug itself, it may become exposed as the surrounding rock is eroded away. Such erosional remnants are referred to as volcanic necks. Classic examples include Devils Tower in northeast Wyoming* (fig. 1), Ship Rock in northwest New Mexico, and Agathla Peak in Monument Valley, Arizona. Volcanic necks are essentially casts that give us a three-dimensional view of the shape of a volcanic pipe or conduit.

In his upcoming article on Canadian diamonds (in press) Warren Boyd mentions that most of the world's diamonds are found in and mined from two types of deposits: placers (see Rakovan 2004) and kimberlite pipes. Kimberlites are igneous rocks (derived from a volatile-rich, potassic, alkaline magma) in which diamonds are found; these rocks are associated with extinct volcanoes. In the anatomy of a kimberlite pipe (the interior of the kimberlite volcano), the diatreme zone is essentially a volcanic plug or neck; however, it has unique characteristics that are related to its special mechanism of formation.

Diatremes are funnel or carrot shaped, with steep walls that taper at depth (fig. 2). Diatremes can be 1–2 kilometers in vertical length, and their angle of taper is usually 80–85 degrees from horizontal. In horizontal cross section, as would be seen in an aerial view of an exposed diatreme, they are circular to elliptical. Rather than being filled with massive, essentially homogeneous igneous rock, diatremes are composed of a breccia (a mass of angular rock fragments) of volcanic rocks mixed with fragments of host rock, xenoliths of rocks that have been carried up from depth, and even surface sediments (fig. 3). Individual crystals of various minerals (such as plagioclase, olivine, clinopyroxene, hornblende, biotite, and diamond) are also common in kimberlitic diatremes, where they are found embedded in a fine, highly altered, vesicular matrix. These individual crystals either formed from the magma during its ascent (phenocrysts) or were separated from xenoliths that were entrained in the magma (xenocrysts) (Mitchell 1986).

The brecciated texture is a distinguishing characteristic and separates the diatreme zone from the root, or hypabyssal zone, of a kimberlite pipe. Unlike most volcanic plugs (and the root zone of a kimberlite pipe), which form as magma contained within a volcanic conduit peacefully solidifies, a diatreme forms because of an unusual style of volcanism. There are two models for how this volcanic style occurs; however, because a kimberlitic eruption has never been witnessed, there is still some debate about which is correct in the case of kimberlite eruptions (Milashev 1988).

In the first model, the original kimberlite magma, which

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*There are actually different hypotheses for the exact origin of Devils Tower, and the debate continues. For further information see Robinson (1956) and http://www.cr.nps.gov/history/online_books/deto/sec3.htm.

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Figure 2. Schematic cross section of a kimberlite pipe and its associated diatreme. Modified from Harlow (1998).
forms deep within the upper mantle of the earth (more than 150 kilometers below the earth's surface), ascends toward the surface along fractures, faults, and other zones of weakness. Volatiles, especially CO2 and H2O that are present in high concentrations in kimberlite magmas, remain dissolved in the magma at depth because of the high confining pressure. The rate of ascent is thought to be very rapid, on the order of 10–30 kilometers per (Eggler 1989). Thus, as the magma reaches shallower depths, a high pressure is maintained by the force of the rising magma against the rocks above it. At some point, very close to the surface, this “back pressure” can no longer be maintained at a level high enough to keep the volatiles dissolved in the magma. The result is a rapid and violent exsolution of gas, analogous to releasing the pressure on a soda bottle, creating vigorous effervescence. This rapid gas expansion not only forces the conduit through which the magma is moving to expand, but it also brecciates the surrounding country rocks and any other solids entrained in the magma as the gas-dominated eruption reaches the earth's surface. As the erupting fluid transitions into this explosive phase, it is thought to reach supersonic speeds and begins to swirl and churn. The fragments of rock in this swirling mass of gas and magma scour out the funnel-shaped diatreme zone, which is eventually filled in with these fragments to form a cemented breccia after the eruption. This model is considered a magmatic type of eruption—the large volume of associated gas is derived from the magma itself.

Diatremes are not restricted to kimberlitic or lamproitic (a related rock type) volcanics, however. They can form by the eruption of any magma type, and this leads to the second model for how diatremes may originate. Of course, both mechanisms may be active, depending on the magma composition, and the nature of the country rock into which it is emplaced. The second diatreme-forming process is known as a phreatomagmatic eruption. In this case, the large volume of associated gas is not from the magma but is created by the flash boiling of water into which the magma is introduced. This can occur either when a magma passes into a water-saturated sediment or porous rock or if it is ejected into a body of surface water, such as a lake. In either case the flash boiling of the water by the magma leads to a steam-driven eruptive style similar to that described for kimberlitic volcanism above. The result is also the formation of a diatreme. Examples of diatremes associated with basaltic volcanics are Kilbourne Hole, New Mexico, and the numerous phreatomagmatic volcanoes of the Eifel area of Germany.

To learn more about diatremes associated with kimberlite eruptions there are two useful Internet sites that include animations; these can be found at the Web site of Diamondex Resources, Ltd. (http://www.nrcan.gc.ca/mms/diam/kimberlite-en-kimberlite.swf), and at an extensive site about diamonds and their formation at the American Museum of Natural History (http://www.amnh.org/exhibitions/diamonds/how.html), for which there is also a companion book (Harlow 1998).

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