BLACK HILLS GEOLOGY

1. **Archean Rocks**
   A. Present in the Black Hills but are limited to two small areas
      1. Along Little Elk Creek (NE)
      2. Near Bear Mountain (SW)
   B. Part of the Wyoming Archean province
   C. Both have granites (tonalites) that are about 2.5 billion years old
      • These granites intrude older high grade metasedimentary successions.
   D. Likely the foundation for the rest of the Precambrian rocks in the Black Hills. These rock are unconformably overlain by younger metasedimentary rocks.

2. **Proterozoic Rocks**
   A. 99% of all exposed Precambrian rocks in the Black Hills area
   B. Consists of metasedimentary, metavolcanic and intrusive granitic rocks
   C. At least two depositional successions
      1. ~2.2 bya
      2. ~1.9-2.0 bya
   D. As many as five deformational and metamorphic events have been documented
      • typically tightly folded and have well-developed, steeply inclined foliation
      • dominant structural grain is NNW
   G. Intruded by the ~1.7 bya post tectonic, S-type Harney Peak Batholith
   H. Part of the Trans-Hudson belt

3. **Summary of Major Mapped Early Proterozoic Rocks**
   A. Xqi
      • Occur in the Nemo area
      • Metaconglomerate, Quartzites, BIF. Some conglomerates are uraniferous
      • Deposited in a rift environment
      • Unconformably overlie the Little Elk Granite
      • Intruded by the 2.17 bya gabbroic, gravity differentiated Nemo Sill (Xmg)
   B. Xgf
      • Exposed in the Nemo area
      • Conglomerate, quartzite, marble (shallow water facies)
      • Lateral equivalent to southern units?
   C. Xpb
      • Greenstones (pillowed), BIFs, slates
      • 1.97 bya
      • Homestake Formation and associated rocks in the Lead and Rochford areas
      • Occurrence of Black Hills gold.
   D. Xgw-Xif-Xcg-Xbs-Xms
      • Schists, BIFS, metagraywackes, metaconglomerate, quartzite, phyllite, metatuff, minor greenstones. Mainly deep marine sedimentary and volcanic rocks.
      • Graywackes are the most abundant
      • Conformably overlie Xpb
      • Present in the southern and eastern Black Hills

E. Xp
   - Youngest metasedimentary succession
   - Mainly poorly exposed black slate and phyllite
   - Repeated several times by folding
   - Present in the Deerfield Lake and Pactola Lake areas in the western Black Hills

F. Harney Peak Granite
   - Present in the southern Black Hills including Mount Rushmore
   - Topographic high of the uplift, very resistant rock
   - Associated pegmatites
   - Contact metamorphic zones
   - Mechanism of intrusion has a significant effect on the country rock

4. Dominant Structures in Black Hills Precambrian Rocks

1. Primary structures
2. Cleavage/Schistosity
3. Lineations
4. Folds
5. Ductile shear zones

General Characteristics Of Black Hills Strata

Newcastle Sandstone (Cretaceous) - named for town of Newcastle, Wyoming
   A. Light yellow-brown to gray sandstone
   B. Thin and discontinuous in eastern Black Hills
   C. Low cliff and hogback former

Skull Creek Shale (Cretaceous) – named after Skull Creek, Wyoming
   A. Dark gray shale
   B. Soft and platy
   C. Valley former

Fall River Sandstone (Cretaceous)
   A. Chocolate brown to gray sandstone
   B. Cross-bedded and current rippled
   C. Thin bedded
   D. Cliff and low hogback former

Lakota Formation (Cretaceous) – named after Lakota Peak in southeastern Black Hills
   A. Light yellow-brown sandstones and gray mudstones
   B. Cross-bedded and current rippled
   C. Petrified wood in places
   D. Major cliff and hogback former

Morrison Formation (Jurassic) – named after town of Morrison, Colorado
   A. Varicolored mudstones and local channel sandstones

B. Slope former, generally covered

Unkpapa Sandstone (Jurassic)- named after Unkpapa Peak in southeastern Black Hills

A. White friable sandstone
B. Massive bedding, locally cross-bedded
C. Pinches out to northwest of Rapid City
D. Moderate to strong cliff former

Sundance Formation (Jurassic) – named after town of Sundance, Wyoming

A. Yellow and red sandstones with green and gray shales
B. Calcareous units - beleminite fossils
C. Hulett Member - rippled yellow to orange ss
D. Cliff and slope former

Spearfish Formation (Triassic) – named after town of Spearfish, South Dakota

A. Red mudstones, sandstones, and white gypsum
B. Thick-bedded, massive
C. Major valley former

Minnekahta Limestone (Permian) – named with Sioux word for "hot springs"

A. Gray, banded or laminated limestone
B. Often has small, sharp folds
C. Major cliff and dip slope former

Opeche Shale (Permian) – named with Sioux word meaning "battle creek"

A. Orange-red, locally purple, mudstones and minor ss.
B. Valley or slope former

Minnelusa Formation (Pennsylvanian – Permian) – named with Sioux word for "rapid creek"

A. Gray, yellow-brown, and red colors; cyclic ss, sh, and ls
B. Major bedding horizontal, some beds cross-bedded
C. Red, yellow and gray chert nodules in upper part
D. Major cliff former for thick sandstone units

Pahasapa Limestone (Mississippian) – named with Sioux word for "Black Hills"

A. Massive, gray to yellow-brown limestone and dolomite
B. Dirty gray weathered surface
C. Dark gray, black and brown chert nodules locally
D. Horizontal bedding
E. Many caves and solution cavities, large calcite crystals
F. Major cliff former

Englewood Limestone (Devonian – Mississippian) – named for Englewood Station south of Lead, South Dakota

A. Pink to violet colored limestone, shaly at base
B. Horizontal bedding

C. Many vugs, some white chalcedony nodules and geodes
D. Solitary corals and brachiopods
E. Slope former

Whitewood Formation (Ordovician) – named after Whitewood Canyon near Deadwood, South Dakota

A. Mottled yellow-brown and pink dolostone
B. Horizontal bedding
C. Hackly weathered surface
D. Chain coral and receptaculites
E. Cliff former

Winnipeg Formation (Ordovician)

A. Roughlock Mbr. (upper unit) - brown siltstone w/abundant trace fossils
B. Icebox Mbr. (lower unit) - soft green shale, locally red
C. Slope former, generally covered

Deadwood Formation (Cambrian) – named after town of Deadwood, South Dakota

A. Three major units: basal unit of qtz. ss. with local basal conglomerate; shale and flat-pebble limestone conglomerate in middle unit; qtz. ss. upper unit (Aladdin Member), with Scolithus trace fossils
B. Red-brown color
C. Horizontal bedding
D. Glauconite common
E. Cliff (ss.) and slope (sh) former

PLATE I: General Outcrop and Composite Stratigraphic Sections of the Black Hills Area

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		ROCK UNITS	THICKNESS (maximum)	LITHOLOGY	ENVIRONMENT	FOSSIL SUCCESSION	A GOOD PLACE TO VIEW THE ROCKS
CENOZOIC	HOLOCENE 10,000 yrs.	Unnamed units	30 feet	Sand and gravel	Streams and dune fields	*Bison* and human artifacts	Lowest terraces along the region's creeks
	PLEISTOCENE 2 mya	Most units unnamed	50	Sand and gravel	Stream and dune fields but no glaciers in Black Hills	*Bison, Equus, Mammuthus*	Along Fall River and at the Mammoth Site in Hot Springs
	PLIOCENE 5 mya	Unnamed unit	20	High terrace gravels	Streams flowing to the southeast or to Hudson Bay	*Titanotylopus*	Very highest terraces in Black Hills
	MIOCENE	Ogallala Fm.	1000	Light gray sandstones	Stream and floodplain; seasonally wet and warm	*Teleoceras, Merycodus, Neohipparion, Nannippus, Ustatochoerus*	Porcupine Butte north of Wounded Knee, SD
		Rosebud Fm.	270	Pink siltstones	Eolian dominated plains	*Merycochoerus, Merychyus*	Exposure in vicinity of Porcupine Butte
	24 mya	Harrison Fm.	180	Tan, friable, fine sandstones and siltstones	Local streams and eolian plains	*Promerycochoerus, Desmatochoerus*	Along Wounded Knee-Manderson road
	OLIGOCENE	Monroe Creek Fm.	100	Tan cliff-forming sandstones and siltstones	Stream and plains with eolian cover	*Allomys, Promylagaulus*	West of highway at Porcupine, SD
		Sharps Fm.	350	Tan siltstone with calcareous concretions and a basal tuff	Floodplain and stream; seasonally dry	*Palaeocastor, Nanotragulus, Cyclopidius, Diceratherium*	Cedar Pass Badlands National Park
	34 mya	Brule Fm.	460	Mudstones with color bands from paleosols and sandstones	Floodplain and stream; seasonally dry and warm	*Merycoidodon, Stylemys, Palaeolagus, Leptauchenia, Ischyromys*	Cedar Pass and Conata Picnic Grounds Badlands National Park
	EOCENE	Chadron Fm.	180	Bentonitic claystones with sandstones and conglomerates	Stream and floodplain; woodlands; warm amd subhumid	*Brontops, Alligator, Mesohippus, Leptomeryx*	Yellow Mounds Overlook Badlands National Park
	58 mya	Northern Hills intrusives		Rhyolite, phonolite, trachyte, quartz latite often porphyritic	Major erosional interval and intense weathering of rocks exposed in the Black Hills uplift	No fossils	Bear Butte, Devils Tower, Homestake open cut, Terry Peak, Bridal Veil Falls in Spearfish Canyon
	PALEOCENE	Tongue River Fm.	400	Yellow sandstone and light colored clays	Stream and shallow ponds; warm and wet	Fossils rare	Cave Hills, north of Buffalo, SD
		Cannonball Fm.	225	Sandstone and gray-green shales with concretions	Very shallow nearshore marine	*Ophiomorpha*	Riley Pass, Cave Hills
	66 mya	Ludlow Fm.	350	Somber gray sandstones with bentonitic claystones and lignite	Coastal plains with streams and coal swamps; warm and wet	Taxodiaceae	Cave Hills, north of Buffalo, SD
MEZOSOIC	CRETACEOUS	Hell Creek Fm.	425	Somber sandstones with bentonitic claystones and zones of iron carbonate	Upper delta plain rivers and flood basins; warm and wet	*Tyrannosaurus, Edmontosaurus, Triceratops, Metasequoia*	Crow Butte US 85 north of Center of the Nation
		Fox Hills Fm.	200	Gray shale with concretions and light colored sandstone	Marginal marine and nearshore marine	*Sphenodiscus, Hoploscaphites*	Moreau River Valley along SD Highway 73
		Pierre Shale	2000	Dark gray shale with calcareous concretions and bentonites	Shallow marine restricted circulation	*Baculites, Placenticeras, Didymoceras, Dakoticancer*	South and east of Buffalo Gap, SD
		Niobrara Fm.	200	Calcarous shale to chalk with bentonites	Shallow marine	Ostreid and inoceramid clams, coccoliths	Behind Trailside convenience store SD 44 southeast side of Rapid City
		Carlile Shale	720	Light gray shale with bentonites	Shallow marine	*Scaphites, Prionocyclus, Collignoniceras, Inoceramus*	Belle Fourche Reservoir
		Greenhorn Limestone	320	Calcerous shale to flaggy ridge forming limestone with bentonites	Shallow marine with extensive mollusk banks	*Mytiloides*	South of Fairburn, SD and Belle Fourche Reservoir
		Belle Fourche Shale	565	Dark gray shale with bentonites	Shallow marine with restricted circulation	Fish scales	Hills south of SD School of Mines and Technology
		Mowry Shale	225	Dark siliceous shale with bentonites	Shallow marine with restricted circulation	Fish scales	Between St. Onge and Fruitdale, SD
		Newcastle Sandstone	60	Sandstone and claystone with bentonite and lignite	Coastal lowland streams and floodbasin	Fossils rare	East and north of M-Hill in Rapid City, SD
		Skull Creek Shale	275	Dark gray shale	Shallow marine with restricted circulation	Foraminiferans	Below Newcastle outcrops in Rapid City, SD
		Fall River Sandstone	200	Massive to slabby tan quartz sandstone	Transgressive marine shoreline	Fossils rare	First sandstone along US 18-385 west of Maverick Junction, SD
	145 mya	Lakota Formation	500	Cross-bedded, rusty yellow quartz sandstone with limestone lenses	Stream, lake, and tidal flats	*Cycadeoidea*, Gymnosperm wood, Theropod footprints	Dinosaur Park, Rapid City, SD

	JURASSIC	Morrison Fm.	100	Variegated mudstones and gray sandstones	Floodplain and stream; seasonally dry and warm	Ostracodes, *Barosaurus*, *Allosaurus*, *Camarasaurus*	Six to 13 miles west of Sundance, WY along I-90
		Unkpapa Sandstone	265	White to bright yellow and red fine sandstone	Shoreline dunes	No fossils known	Pink to maroon sandstone on east side of Hot Springs, north side of highway
	208 mya	Sundance Fm.	350	Red and gray green shale, white to yellow sandstone andthin limestones	Fluctuating near shore marine, shoreline and lagoon	*Pachyteuthis*, *Pentacrinus*, *Amaltheus*	Northwest side of Sturgis, Sundance to Hulett, WY
	TRIASSIC	*IMPORTANT EROSION EPISODE*					
PALEOZOIC	245 mya	Spearfish Fm.	800	Red beds mostly siltstone with gypsum layers at top and base	Marginal marine to continental; hot, dry	Fossils rare, stromatolites, bivalves	Vicinity of Reptile Gardens south of Rapid City
	PERMIAN	Minnekahta Limestone	40	Pink to gray thinly bedded limestone	Shallow marine	*Acrolepis*, *Pteria*	Along US 16 south of Reptile Gardens as highway turns going up hill
		Opeche Shale	130	Red siltstone, shale and sandstone	Marginal marine to marine	Fossils rare	On north side of US 16 beyond Minnekahta outcrops
	286 mya	Minnelusa Fm.	725	Yellow to red sandstone, shale and limestone	Marine to marine margins	Conodonts, fusulinids, *Listracanthus*	Vicinity of Cleghorn Fish Hatchery in west Rapid City, SD
	PENNSYLVANIAN 320 mya	*IMPORTANT EROSION EPISODE*					
	MISSISSIPPIAN	Pahasapa Limestone	600	Dolomitic massive limestone with caves in the upper part	Shallow marine	*Syringopora*, *Zaphrentis*, spirifer brachiopods	Spearfish Canyon and White Gates along Little Elk Creek west of I-90 and northwest of Piedmont, SD
	360 mya	Englewood Limestone	50	Basal shale and dark pink to buff limestone	Shallow marine	*Fenestrella*, *Lingula*, *Cyrtina*, *Zaphrentis*, graptolites, conodonts	East of intersection of US 85 and 14A near Deadwood
	DEVONIAN 408 mya	*MAJOR EROSION EPISODE*					
	SILURIAN 438 mya						
	ORDOVICIAN	Whitewood Fm.	70	Light yellow dolomite and limestone	Shallow marine	*Endoceras*, *Halysites*, *Maclurites*, *Receptaculites*, conodonts	East of US 85 and 14A near Deadwood
	505 mya	Winnipeg Fm.	70	Green shale and upper silstone	Shallow marine	Conodonts	East of US 85 and 14A near Deadwood
	CAMBRIAN 570 mya	Deadwood Fm.	400	Massive red brown to light yellow sandstone, glauconitic shale, and flat pebble conglomerates. Local basal conglomerates	Transgressive shoreline and shallow marine	*Skolithos*, *Lingulella*, *Hyolithes*, *Dikelocephalus*, *Dicellomus*, *Crepicephalus*	In Deadwood, SD
PRECAMBRIAN		*MAJOR EROSION EPISODE, THE GREAT UNCONFORMITY*					Deadwood, SD between Rodeo Grounds and town on south side of valley
	PROTEROZOIC	Very complex set of formations	>25,000 feet	The youngest Precambrian rocks: 1.7 billion years old (byo) **HARNEY PEAK GRANITE and PEGMATITE**	Deep instrusives	No fossils recognized from the Precambrian rocks of this region	Harney Peak, Needles, Custer State Park, Mt. Rushmore
	2.5 bya			Mid-sequence metamorphosed sedimentary and igneous rocks that include: SCHIST, SLATE, QUARTZITE, BASALT & GABBRO, METAGRAYWACKE, METACONGLOMERATE, BANDED IRON FORMATION. These are 1.9 to 2.2 byo.	Schists and other metamorphics orignally were sediments that accumulated in active fault basins with attendant intrusives and some igneous flows		Schist at car tunnel north of Keystone, SD. Homestake Mine open cut in Lead, SD—a very spectacular outcrop. Metaconglomerate and quartzite along Nemo Road, 2.2 miles southeast of Steamboat Picnic Grounds. Banded Iron Formation, 0.3 miles southeast of Nemo, SD on west side of road
	ARCHEAN 4.6 bya	Little Elk Granite		2.5 byo Little Elk Granite	Granite which formed at some depth and intruded into a coarse clastic sequence	No fossils recognized	One mile west of Dalton Lake, north of Nemo, SD

Tertiary Igneous Rocks of the Black Hills Region

Timing of Igneous Activity

Igneous rocks of Tertiary age, mostly intrusive in character, are present in the northern end of the Black Hills uplift. Similar intrusions at Sundance, Devil's Tower, and Little Missouri Buttes, Wyoming appear to be related in terms of rock types and time of emplacement to those of the Black Hills. Most of the igneous activity is believed to have been concurrent with the first phase of uplift. Devil's Tower and the Little Missouri Buttes were intruded into upper Cretaceous beds. Igneous-rock cobbles and boulders occur in Oligocene gravels in the vicinity of Lead and Deadwood (Jagger, 1901, p. 185). Thus, field evidence places the time of intrusion at some time between the end of the Cretaceous and the beginning of the Oligocene. K-Ar isotopic age dates on the intrusions range from 40.5 + / - 1.6 to 58.9 + / - 1.8 million years, indicating an Eocene age (Basset, 1961 and McDowell, 1971). Uplift that elevated the Oligocene gravels is believed to have occurred during the Miocene.

Eocene Intrusive Rock Types

The rock types represented by the Eocene intrusions consist of, in decreasing order of abundance, a normal calc-alkaline series of silica-saturated and oversaturated rocks including rhyolites, both porphyritic and non-porphyritic, and porphyries of dacite, quartz-latite, latite, andesite and trachyte. Also present, but in considerably less quantity, are some peralkaline and alkaline rocks, including aegirine rhyolite (called grorudite by Darton and Paige) and phonolite porphyry, the latter being undersaturated. A standard reference with petrographic descriptions and a geologic map is given by Darton and Paige (1925). DeWitt and others (1986) present more recent maps and descriptions. A guidebook edited by Rich (1985) contains considerable information on the structure and petrography of the intrusions.

The intrusive rhyolites are white or light gray in color, aphanitic, with few or no phenocrysts, and usually contain very minor or no mafic minerals. They are easily recognizable in the field by their color and their uniformly fine texture that makes them appear somewhat porcelainous. They also tend to weather into a brown-stained rubble of coarse, angular pieces. They can be observed in many roadcuts as sills and dikes. Extensive sheets of rhyolite up to several hundreds of feet thick and mapped for distances up to three miles have been intruded into the Deadwood Formation and are common in the areas north and south of Deadwood and Lead. In addition, Noble (1948) has reported that there are some high-potash (approximately 5-7% K_2O) and very high-potash (approximately 9-13% K_2O) rhyolite dikes that occur in the Homestake Mine. (Normal rhyolites contain about 3-5% K_2O).

The rhyolite porphyries and quartz-latite porphyries (called quartz monzonite by Darton and Paige) usually have a white, light gray or light green aphanitic groundmass when fresh, but this is often stained to a red or reddish-brown color by weathering. Phenocrysts are abundant and consist of quartz, K-feldspar and plagioclase. Varietal minerals include biotite and hornblende in varying stages of alteration, often altered enough to leave stained pits where the minerals had been. The two rocks are difficult to distinguish positively in the field, but in general the quartz latite porphyries are somewhat darker and contain more mafic minerals than the rhyolite porphyries. Plagioclase is albite in the rhyolites, but is more calcic in the quartz latites. These porphyritic intrusions occur most commonly as stocks and dikes and less commonly as sheets. They are most abundant in areas east and west of the rhyolites.

Trachyte porphyry and latite porphyry (called monzonite by Darton and Paige) grade to andesite porphyry and are not as abundant as the above rocks. Latite porphyry occurs in two large intrusions, one southeast of Deadwood and the other on Redpath Creek, west of Lead. The rocks are medium gray and porphyritic, lacking the quartz that is common in the other rocks. They also tend to be more mafic, with hornblende common, and are more highly altered than the more silicic rocks.

Two types of peralkaline/alkaline rocks occur, the aegirine rhyolites and the phonolite porphyries. Aegirine rhyolite porphyries are soda-rich rocks in which the excess soda over that needed to make feldspar appears in the form of sodium pyroxenes, aegirine or aegirine-augite. The rocks are white or light gray to light green in color and are composed of various proportions of quartz, albite, orthoclase and pyroxene phenocrysts in an aphanitic groundmass. These rocks and the phonolites are distinctly more fresh than the calc-alkaline rocks in this area. Aegirine rhyolite porphyries occur mainly in thick sheets and laccoliths that are concordant with the invaded Paleozoic sediments.

Phonolite porphyry, the hypabyssal equivalent of nepheline syenite, is an alkaline undersaturated rock. It contains excess soda over both alumina and silica needed to make feldspar, resulting in the presence of both sodic-pyroxene and feldspathoids. Most of the Black Hills phonolites are porphyries with aphanitic groundmass, although the centers of larger intrusions may be medium-grained phaneritic. The intrusion at Bridal Veil Falls, Spearfish Canyon, is coarse enough to be called a nepheline syenite. Phenocrysts are usually alkali-feldspar and aegirine or aegirine-augite, and rarely nepheline. Feldspathoids vary in kind from one intrusion to another and may include nepheline, analcite, sodalite, nosean and hauyne. These are found in the groundmass along with feldspar and pyroxene. In quantity the feldspathoids vary from the 25% nepheline in the Spearfish Peak intrusion down to none in the Sugarloaf Mountain laccolith southwest of Lead. Technically, when the feldspathoid content is below 10%, the rocks should be called soda-trachytes, but in the field these are indistinguishable from the true phonolites and all are lumped together. Sphene is a distinctive accessory mineral; magnetite and apatite also occur. Three areas contain amphibole-bearing phonolites that differ chemically and mineralogically from the other phonolites (Kirchner, 1987). Phonolites occur mainly as stocks, laccoliths and sills (Jagger, 1901; Darton and Paige, 1925; Noble 1952).

The phonolite porphyries comprise only a small percentage of all of the intrusive rocks in this area, but they stand out among the rest. They have a distinctive color, being dark brown or greenish gray to dark green. A greasy luster is common on a fresh surface. The weathered surface is most often gray, as opposed to the red-brown of all of the other rock types. The phonolites are hard and resistant, frequently producing cliffs, knobs or ridges in outcrop. Weathering of thin sills, or near the margins of massive intrusions, commonly produces a distinctive platy appearance in which the plates form parallel to the trachytic flow structure.

Two occurrences of lamprophyre dikes have been reported in the Black Hills. Darton and O'Hara (1905) (also Welch, 1974) reported augite lamprophyres associated with nepheline syenite in the Tinton mining district, and Kirchner (1979) reported a carbonate-rich lamprophyre associated with phonolite in Squaw Creek.

Occurrence and Relationship of the Intrusions

The intrusions occur in the form of dikes, sills, laccoliths, stocks and forms not easily classifiable in normal terms. Irving (1899) noted that the structural configuration of the intrusions in the Black Hills depended, in most cases, on the type of invaded rock. Dikes are almost solely confined to areas in which the host rocks are Precambrian metamorphic rocks with pronounced foliation, most of which is nearly vertical. Within the Cambro-Ordovician section there are several horizons in which the rocks are thin-bedded and flaggy, providing easy access to invading magma. Intrusions into this part of the section are usually sills that may be thin as one foot or as thick as several hundred feet. Intrusions coming up through the section frequently change from vertical dikes in the schists to sills when they reach the Deadwood Formation. Examples of this can be seen in the exposed cut at the Homestake Mine. The massive Pahasapa and Minnelusa Formations present a formidable barrier to upwelling magma and may force the magma to spread out laterally while doming the overlying sediments, forming laccoliths (Jagger, 1901). If the pressure of the magma is sufficient, the magma may punch through the overlying rock. Stocks are formed where massive quantities of magma have invaded the schists or other igneous rocks or have punched up through the Pahasapa or higher formations. Noble (1952) believes that the so-called "laccoliths of the Black Hills" are uncommon in the classic sense of the term "laccolith" and that most of these intrusions are really stocks that have been forcefully emplaced, crosscutting the invaded rocks while doming the overlying sediments. According to him there is not much evidence that the intrusions with domed roofs actually have concordant floors. To this is can be added that in cases where the floors of "laccoliths" are exposed, such as the Sugarloaf Mountain intrusion (along US 85, 2 1/4 miles southwest of Lead) and the Spearfish Peak phonolite, the overlying rocks have been removed by erosion so that their structural configuration cannot be determined. They may be thick sills.

The magmas were intruded at a shallow depth, where the host rocks were relatively cool and the heat from the magma could dissipate rapidly. This is supported by the consistent development of aphanitic textures in all but a few intrusions. Glass is present at the contacts of some intrusions. Contact metamorphism is rarely present beyond minor baking, which also supports the idea of shallow intrusion. According to Darton and Paige (1925) there was a possible range of 3825 to 6500 feet of sedimentary cover above the Pahasapa limestone to the unconformity at the base of the Tertiary. The amount of sediment missing above the unconformity is unknown. Pressure at these depths is less than one kilobar.

Little detailed work on the petrogenetic relationships of these rocks has been done. Field evidence and the relative freshness of the phonolites and grorudites indicates that these are the youngest of the rock series. However, there are cases in which phonolites are cut by rhyolite dikes. Most of the K-Ar dates available are for the phonolites. There is an insufficient number of such dates on other rock types to show the extent of any time gap that might exist between the phonolites and the other intrusive rocks.

The different chemical and mineralogical characteristics that separate the alkaline phonolites and the peralkaline aegirine rhyolites from the other rocks might suggest that at least two different parent magmas have been involved in the genesis of the Eocene intrusions (Kirchner, 1971). Indeed, because of the improbability of deriving an undersaturated residual magma from a source that produced copious quantities of oversaturated rocks, it is unlikely that the phonolites are genetically related to the other intrusions. The possibility of producing an undersaturated rock from an oversaturated magma by limestone assimilation and its resulting desilication of the magma is ruled out by the lack of limestone associated with most of the phonolites and by the lack of calcic minerals in the phonolites. Also, chemical trends of the phonolites and aegirine rhyolites do not coincide with those of other rocks, and strontium isotopes indicate separate origins (Beintema, 1986). It is more probable that the calcalkaline magma originated by partial melting of sialic crust with subsequent differentiation yielding the various saturated and oversaturated rock types. The high-potash rhyolites may have formed as part of this differentiation process (Noble, 1948), but more likely represent a special igneous event or process. The phonolite magma originated separately by partial melting of upper mantle material (Kirchner, 1971 and 1993). Parent magmas may have been lamprophyric for some phonolites and alkali olivine basaltic for others, with subsequent fractionation. However, there are many unanswered questions regarding the origin and relationships of the phonolites. The aegirine rhyolites can be tied to the phonolites of lamprophyric parentage by petrographic and chemical characteristics (Kirchner 1993 and unpublished data).

Volcanic Rocks

The Tomahawk Country Club, near the junction of US 385 and the Nemo Road, is the center of a roughly-circular area, one-half mile in diameter, of volcanic rocks. These include well-sorted tuffs, heterolithologic breccias and rhyolitic breccias. A large block of obsidian is incorporated in one of the breccias, indicating surface extrusion. Inclusions of Cretaceous shale indicate the extent of sedimentary cover at the time of eruption. This complex is probably a diatreme, back into which much material has collapsed. About eight miles to the east, two small areas contain rhyolitic breccias with clasts of schist, obsidian and limestone. These are either volcanic pipes or diatremes that vented to the surface (Kirchner, 1991). More extensive volcanism in the area has not been reported.

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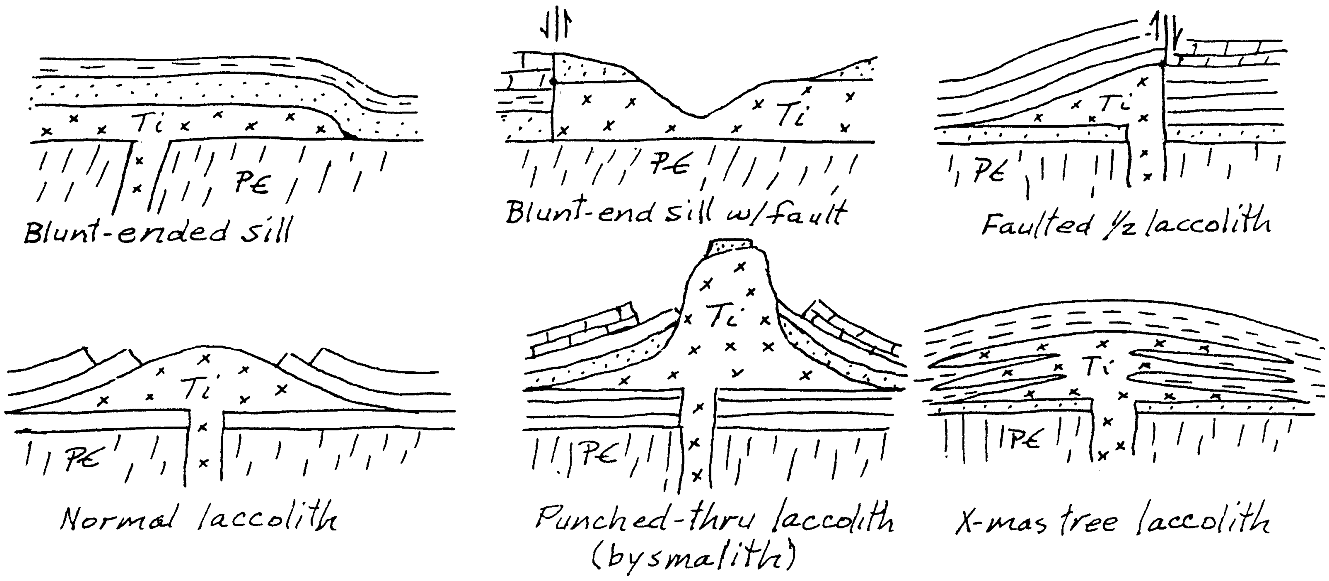
Style and geometry of typical igneous intrusions in the Black Hills region



Common problems interpreting the subsurface geometry of igneous intrusions in the Black Hills region.

Note that the Precambrian basement is not faulted. All faults within the rocks dome by intrusions are kinimatically linked to the intrusion. Think about this when drawing your Whitewood Peak sections.