THE ORIGIN OF WATERFALLS IN THE BLACK HILLS, SOUTH DAKOTA

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ABSTRACT

We studied the largest waterfalls in the Black Hills to better understand the geologic and hydrologic reasons for their existence. The waterfalls studied include: an unnamed falls on the Cheyenne River above Angostura Reservoir, "Big Falls" on Battle Creek below Keystone, "Bridal Veil Falls" on Rubicon Gulch along Spearfish Canyon, "Spearfish Falls" on Little Spearfish Creek near Savoy, "Roughlock Falls" on Little Spearfish Creek above Savoy, the waterfalls of Fall River below Hot Springs, and "Cascade Falls" on Cascade Creek. The geology of each waterfall was determined, their heights were measured, and cross sections were constructed. The discharge over each waterfall was obtained from USGS records; where no records were available the discharge was estimated.

The waterfalls form in primarily two different ways. First, where more resistant rock units are exposed, this resistant ledge of rocks forms rapids and/or waterfalls. Thus a "knickpoint" is formed in the longitudinal stream profile. Second, some waterfalls form where calcareous-tufa is deposited in the stream bed. This usually happens below springs draining the Madison Limestone. The calc-tufa deposits typically accumulate within a mile below the spring, in a reach that already contains rapids. The rapids further encourage the outgassing of carbon dioxide, leading to the deposition of calcite and/or aragonite.

Data compiled in this research may be used to help understand the geologic processes that created these waterfalls and help preserve them as aesthetic resources for future generations.

INTRODUCTION

The Black Hills contains several significant waterfalls. They are located in various geologic environments (Fig. 1). The seven waterfalls studied in this investigation are believed to be the largest. Listed alphabetically they are: (1) Big Falls on Battle Creek , (2) Bridal Veil Falls on Rubicon Creek, (3) Cascade Falls on Cascade Creek, (4) Cheyenne River Falls on the Cheyenne River, (5) Fall River Falls on the Fall River, (6) Roughlock Falls on Little Spearfish Creek, and (7) Spearfish Falls on Little Spearfish Creek.

The Black Hills is a Laramide uplift that consists of Paleozoic and Mesozoic rocks unconformably overlying a core of Precambrian metamorphic and igneous rocks.

Waterfalls and rapids are fairly common in the Black Hills, particularly in the Precambrian rocks. Many are on small ephemeral streams. For the pur-

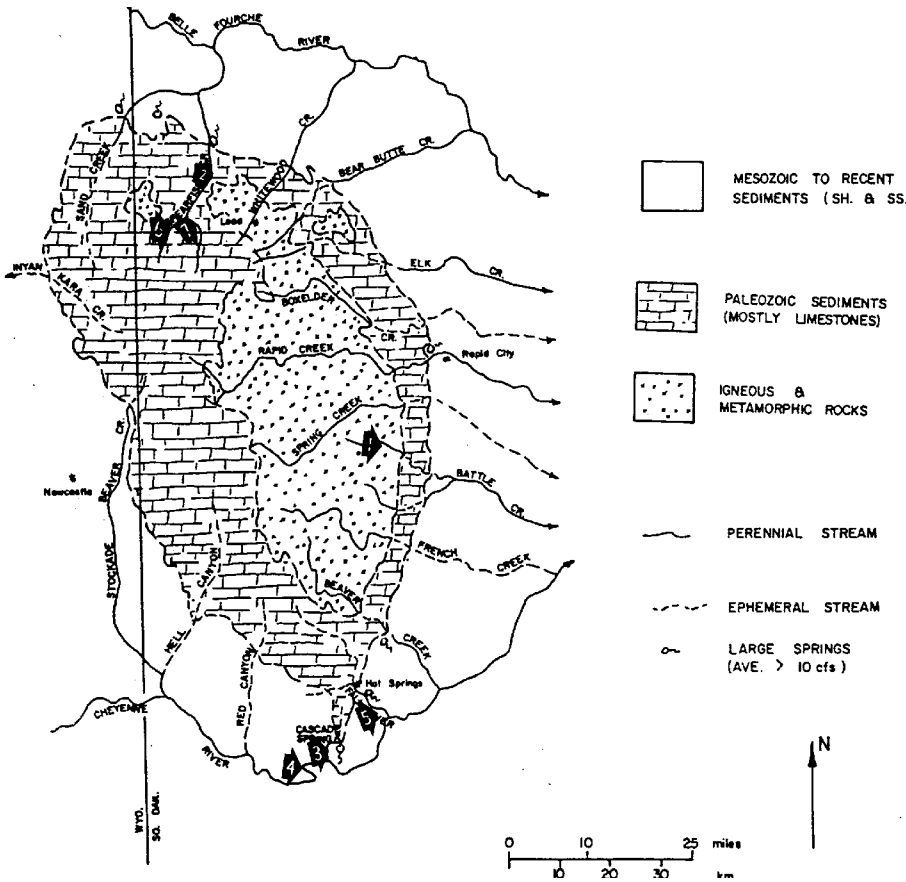

Figure 1. Generalized geologic map of the Black Hills and its relationship to stream flow, showing the location of waterfalls (map taken from Rahn et al, 1981). Numbers 1 to 7 refer to waterfalls shown in Table 1.

pose of this research, only the seven largest known waterfalls were studied. Each waterfall was located on a 7.5 minute topographic map, and the waterfalls measured for height. Geologic cross sections were constructed. Discharge data over each waterfall was obtained from USGS records where available (USGS, 1995); where no records were available the discharge was estimated. The origin of each waterfall was then interpreted.

ORIGIN OF WATERFALLS

Big Falls

Big Falls is located on Battle Creek approximately 4 miles below Keystone (Sec. 11, T 2 S, R 5 E, in the Rockerville 7.5 minute quadrangle). The average discharge over the falls is about 8 cfs (Table 1), based on data taken at Keystone.

Table 1. Waterfall data

Name	Height (ft)	Average discharge (cfs)
1. Big Falls	10	8
2. Bridal Veil Falls	80	0.6
3. Cascade Falls	6	20
4. Cheyenne River falls	3	112
5. Fall River falls	70 total	22
6. Roughlock Falls (upper)	14	13
7. Spearfish Falls	60	13

Big Falls is about 10 ft high (Fig. 2), and is caused by a dike of pegmatite in the Precambrian schist and metagraywake (Rahn, 1987). As Battle Creek eroded into Precambrian rocks it encountered a pegmatite dike which is more resistant to erosion than the surrounding metagraywacke. The pegmatite forms a ledge over which the water falls (Fig. 3).

There are other waterfalls in the Black Hills that are similar to Big Falls. The most noteworthy are the series waterfalls on upper Spring Creek below Sylvan Lake, "Little Falls" on Battle Creek about 1 mile below Big Falls, and the falls on Grizzly Creek about 2 miles above Keystone. All of these waterfalls are due to Precambrian granite outcrops in the stream bed. Rapid Creek in "Dark Canyon" about 5 miles west of Rapid City has drop of approximately 8 ft over a ledge of Precambrian quartzite.

Bridal Veil Falls

Bridal Veil Falls is located where Rubicon Gulch meets Spearfish Canyon (Sec. 9, T 5 N, R 2 E, in the Maurice quadrangle). The height is 80 feet.

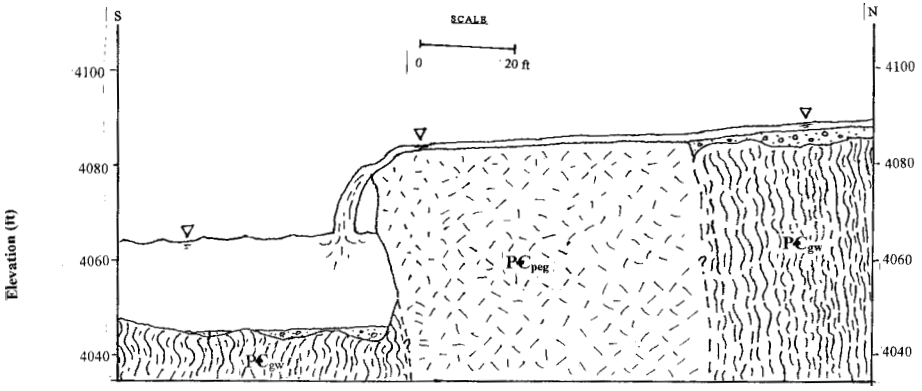

Figure 2. Geologic cross-section of Big Falls on Battle Creek. PC_{peg} is the pegmatite, PC_{gw} is the Metagraywacke.

Figure 3. Photograph of Big Falls.

Discharge data for Rubicon Creek is not available, although some information is published regarding the headwaters at the Richmond Hill gold mine reclamation area. The average discharge of Rubicon Gulch is estimated at Bridal Veil Falls to be 0.60 cfs, based on the 1.36 square mile drainage area, using an value of 2.5 inches runoff from the northern Black Hills (Rahn and Davis, 1993).

Bridal Veil Falls is formed on a portion of a Tertiary nephelene syenite laccolith within the Deadwood formation (Lisenbee, 1995). As the Black Hills uplift and erosion carved out Spearfish canyon the stream encountered the igneous rocks. The falls is formed over the resistant outcrop (or "knickpoint") where Rubicon Gulch meets Spearfish Canyon (Figs. 4 and 5). [Squaw Creek, about 2 miles to the south, has a series of small waterfalls and potholes in the Deadwood Formation. One big pothole is known as the "bathtub".]

Cascade Falls

Cascade Falls is located on Cascade Creek below Cascade Springs (Sec. 30, T 8 S, R 5 E in the Cascade Springs quadrangle). Based on USGS data, the discharge over Cascade Falls is about 20 cfs. The height is 6 ft.

Cascade Creek originates at Cascade Spring, about 3 miles above the falls. The spring is an outlet for ground water in the Madison Limestone and Minnelusa Formation that originates from recharge over a vast area of the southern Black Hills (Rahn and Gries, 1973). As Cascade Creek cut into the sedi-

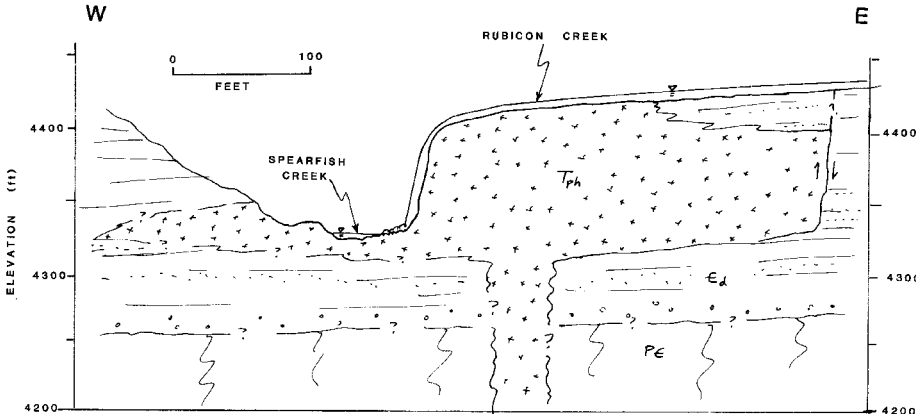

Figure 4. Geologic cross-sectional sketch of Bridal Veil Falls.

mentary rocks on its way to the Cheyenne River it encountered a slightly more resistant layer of sandstone, most likely the Newcastle sandstone (Figs. 6 and 7). Rapids formed over the more resistant sandstone. The calcium carbonate rich water deposited calc-tufa at the falls, adding height to the rapids.

Cheyenne River Falls

Cheyenne River Falls is located in the Black Hills Wild Horse Sanctuary on the Cheyenne River above Angostura Reservoir (Sec. 35, T 8 S, R 4 E, in the Cascade Springs quadrangle).

The discharge of the Fall River at Edgemont, about 30 miles just above the falls, is approximately 112 cfs (Table 1).

The falls is about 3 ft high, and is located where

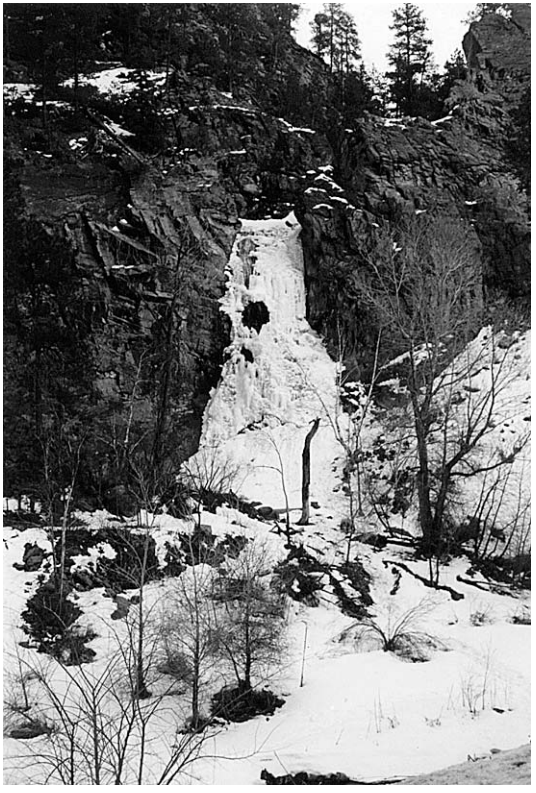

Figure 5. Photograph of Bridal Veil falls, taken in Febuary, 1997. A large ice buildup can be seen.

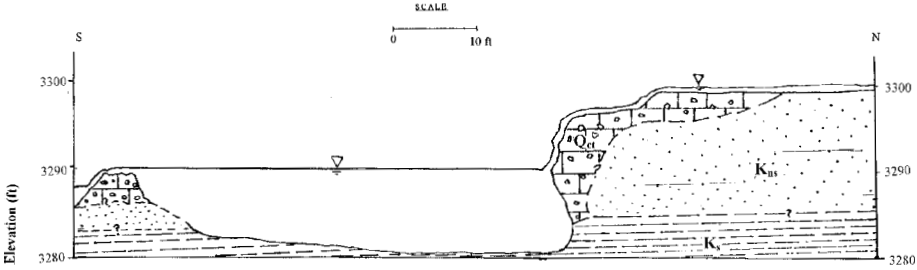

Figure 6. Geologic cross section of Cascade Falls. Q_{ct} is the calc-tufa, K_{ns} is Newcastle Sandstone, and K_s is Skull Creek shale.

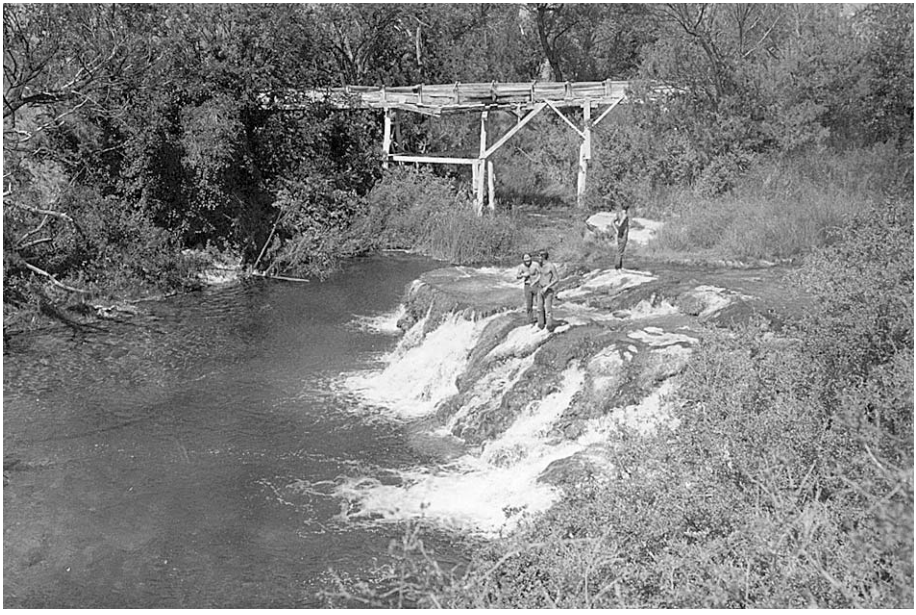

Figure 7. Photograph of Cascade Falls taken in 1970.

a resistant limestone bed crops out in the streambed. As the Cheyenne River cut through the sedimentary rocks flanking the southern Black Hills it encountered the southeasterly dipping Lakota Formation, which includes the Fuson shale member (K_{fs}), the Minnewasta Limestone (K_{mw}), a more resistant member, and deeper units of shale and sandstone shown on Figure 8 as the Lakota formation (K_l). The more resistant Minnewasta limestone forms the falls as a 3 foot high ledge across the Cheyenne River (Fig. 9). Units of shale above and below the sandstone each erode faster than the limestone, leaving it exposed as a waterfall, or "knickpoint" in the stream profile.

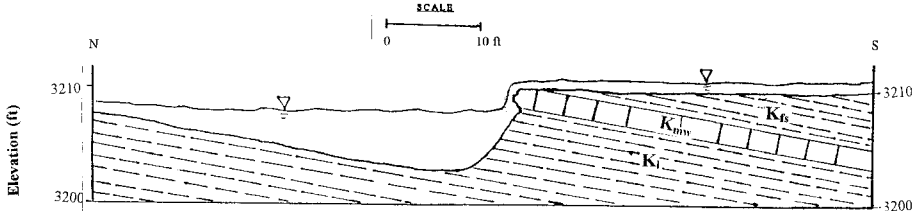

Figure 8. Geologic cross section of Cheyenne River falls. K_{fs} is the Fuson Shale, K_{mw} is the Minnewasta Limestone, and K_l is the Lakota formation.

Figure 9. Photograph of Cheyenne River falls.

Fall River Falls

Fall River falls is located on the Fall River about 5 miles east of Hot Springs (Sec. 33, T 7 S, R 4 E in the Hot Springs quadrangle). Based on the USGS gage at Hot Springs, the discharge over Fall River falls is about 22 cfs.

The waterfalls are actually a serves of falls and rapids, with a total drop of 70 ft within a reach of about 300 ft. As the Fall River exits the Black Hills, it encounters the easterly-dipping Fall River Sandstone. The river eroded the sandstone until the gradient approximately matched the dip of the sandstone, and the water began to cascade and fall over the sandstone, forming several channels that were carved into the bedrock (Figs. 10 and 11). [Three boys

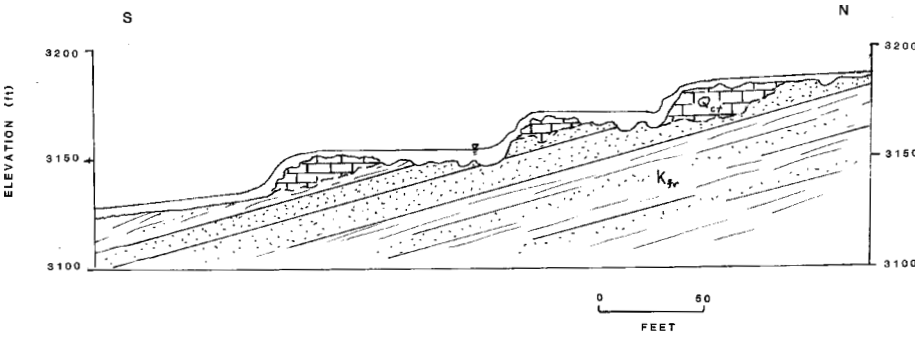

Figure 10. Geologic cross section of the Fall River falls. Q_{ct} is the calc-tufa, K_{fr} is the Fall River Formation.

drowned there in 1995, testiment to the powerful current in some of the potholes.] Because of the high calcite content of the water from the spring ustream at Hot Springs, calc-tufa was deposited on the bedrock falls, and built up in different locations where the water was already falling. Thus the falls is primarily caused by a resistant bedrock units, but is enhanced by the depostion of calc-tufa.

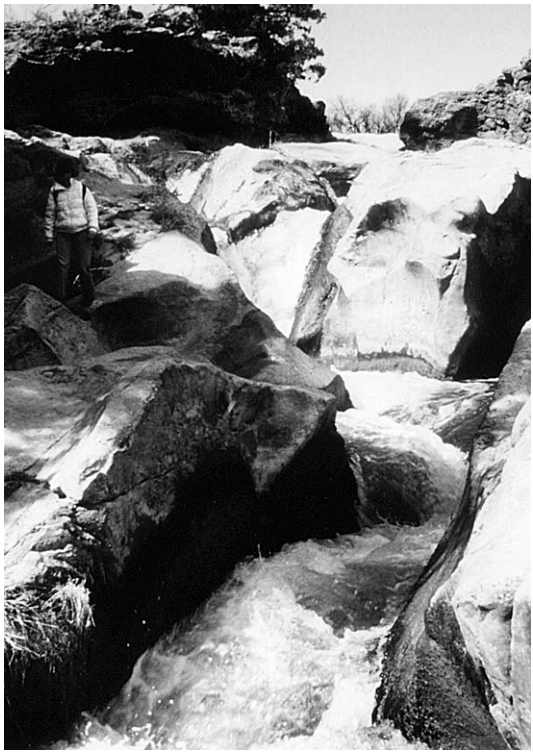

Figure 11. Photograph of Fall River falls.

Roughlock Falls

Roughlock Falls is located on Little Spearfish Creek about 4 miles upstream from Savoy (Sec.36, T 5 N, R 1 E) in the Savoy quadrangle. The water originates from a large spring discharging from the Madison Limestone about 3 miles above the falls. The discharge of Little Spearfish Creek measured at a USGS gaging station below the falls, and is approximately 13 cfs.

Roughlock Falls is formed as a calc-tufa deposit over the Whitewood Formation, a white, buff, dolomitic limestone (Figs. 12 and 13). There are actu-

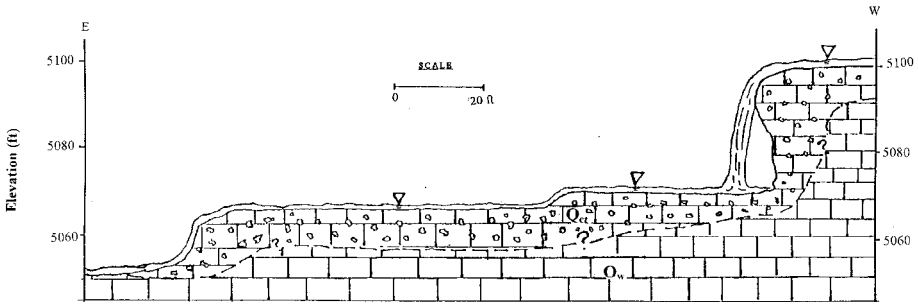

Figure 12. Geologic cross section of Roughlock Falls. Q_{ct} is the calc-tufa, O_w is the Whitewood Dolomite.

ally two waterfalls at this location, the upper one being about 14 ft high. Presumably a ledge in the dolomite initially began the waterfall, encouraging calcite to precipitate, forming a calc-tufa, further building up the waterfalls.

Figure 13. Photograph of Roughlock Falls.

Spearfish Falls

Spearfish Falls is located on Little Spearfish Creek at the intersection of Little Spearfish Creek and Spearfish Creek (Sec. 31, T 5 N, R 2 E, in the Savoy quadrangle). It is about 1 mile below Roughlock Falls.

The discharge over Spearfish Falls is regulated by Homestake Mining Company who for over 100 years have diverted practially all of the water for their mining operations. In 1996 water flowed over the falls for the first time in almost 100 years (Figs. 14 and 15). The discharge above the falls, before the water is removed by Homestake, is about 13 cfs.

Spearfish Falls is formed by a calcareous tufa deposited over the Deadwood formation. Calcareous-tufa is porous calcite and/or aragonite that typically forms downstream from a spring discharging from a carbonate aquifer

(Back et al., 1983). Little Spearfish Creek carries an abundance of dissolved calcite because it was discharged from a carbonate aquifer. As the water encounters the falls the calcite is deposited, over the bedrock ledge, and on top of the alluvium and plants at the rapids.

Conclusion

There are many waterfalls in the Black Hills. We restricted our study to the larger ones. From Table 1 the greatest drop (70 ft) is at the Fall River falls. This drop takes place over a reach of 300 ft, and consequentially is not as impressive as others. The largest single drop (60 ft) is Spearfish Falls on Little Spearfish Creek. In terms of discharge, the Cheyenne River Falls (112 cfs) ranks as the largest. The greatest waterfall in terms of energy release (height times discharge) is the Falls River falls. Aesthetically, they are all beautiful in their own way and deserve to be protected for the enjoyment of everyone.

There are two different types of waterfalls: (1) where a more resistant rock unit is exposed, forming a ledge or knickpoint for water to flow over, and (2) where calc-tufa is deposited below a limestone spring. The waterfalls form

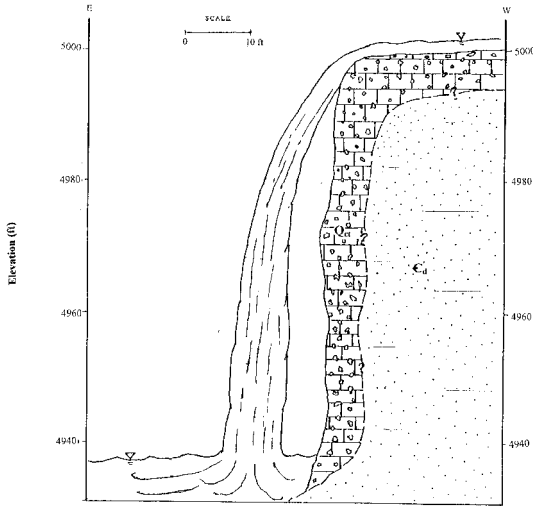

Figure 14. Geologic cross section of Spearfish Falls. Q_{ct} is the calc-tufa, C_d is the Deadwood Formation.

Figure 15. Photograph of Spearfish Falls.

within a few miles of the spring on some reach already possessing rapids or waterfalls, thereby further enhancing the waterfalls.

The geomorphology literature is full of references to the formation of knickpoints supposedly due to the headward erosion from multiple baselevels (Ritter et al., 1995) or "peneplains". This concept has been largely discredited (for example see Rahn, 1971, and references contained therein). The present reseach indicates that the knickponts are due to geological controls and have no relevance to knickpoint recession from baselevel episodes.

While this research is primarily descriptive geomorphology, it also illustrates some fundamental scientific facts, and opens up several questions that could be examined in future research. This research illustrates that a knickpoint or abrupt steepening of the longitudinal profile of stream is formed by a resistant rock unit, and that calcareous-tufa deposits form waterfalls within a few miles downstream from a spring discharged from a carbonate aquifer. Future research could examine the true thickness of calc-tufa deposits on waterfalls and determine the time it takes them for them to form.

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