Proceedings of the Iowa Academy of Science

Volume 67 | Annual Issue Article 42

1960

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Recommended Citation

Coogan, Alan H. (1960) "Geological Age of Soldier Creek Buffalo County, South Dakota," *Proceedings of the Iowa Academy of Science*: Vol. 67: No. 1 , Article 42.
Available at: https://scholarworks.uni.edu/pias/vol67/iss1/42

Geological Age of Soldier Creek Buffalo County, South Dakota

ALAN H. COOGAN[1]

Abstract. A quantitative analysis of data derived solely from maps of Soldier Creek and a comparison with similar data from Good Soldier Creek show Soldier Creek to be a composite stream of several branches which differ in drainage composition and which therefore probably differ in origin. A study of the field evidence bearing on anomalous factors in the quantitative analysis shows Soldier Creek was formed by the capture of several post-Iowan streams by a younger post-Cary stream.

The problem of the age of Soldier Creek is a selected aspect of a larger study undertaken during the summer of 1958 as part of the archeological salvage program of the Smithsonian Institution, Missouri Basin Project. The question of the relative age of Soldier Creek grew out of the investigation of Pleistocene and Recent deposits in the Missouri trench and their relationships to archeological sites under excavation in the Big Bend Reservoir. The usual geological methods of field mapping, lithologic correlation, etc., provided only inconclusive answers to the question of Soldier Creek's age. A quantitative terrain analysis was undertaken then as a second line of attack on the problem.

Appreciation is due the members of the Smithsonian Institution, Missouri Basin Project staff in Lincoln, Nebraska, and especially to William N. Irving, Harold Huscher, and Richard P. Wheeler for their stimulating comment. Dr. Sherwood D. Tuttle, State University of Iowa, introduced me to the subject of quantitative geomorphology.

The quantitative approach to the description and analysis of drainage basins was outlined by Horton (1945), by Strahler (1954), and others, and has been used increasingly since 1945 by investigators interested in ground water, flood control, soil erosion, and a variety of engineering geological problems. To date, however, it has not been used widely in the establishment of a chronological sequence of events or as an aid in the interpretation of historical geology.

PHYSICAL SETTING

Soldier Creek is a small, intermittent, westerly flowing stream about 14 miles long which empties into the Missouri River on its

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left bank near the community of Fort Thompson, Buffalo County, South Dakota. The area of the Soldier Creek drainage basin is about 33 square miles. In the upper reaches the stream flows on the Cretaceous Pierre shale, the bedrock in much of Central South Dakota. Alternatively, in the upper reaches, the stream may flow over well eroded remnants of Iowan till (Flint, 1955; Curtiss and Waddel, 1951). In the lower reaches the stream flows over and cuts through the gravel, sand, and silt of Missouri Terrace 2 (Mt-2) (Figure 2) which is probably Cary in age (Coogan and Irving, 1959).

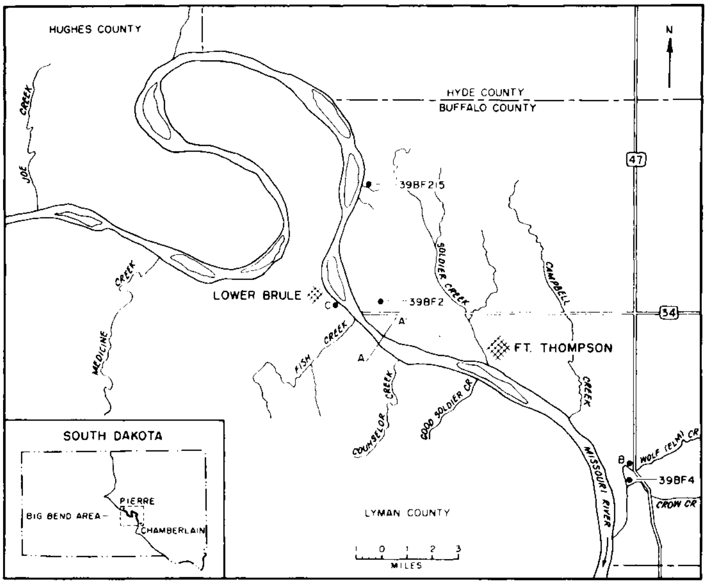

Figure 1. Locality map of the Big Bend and Fort Thompson areas along the Missouri River, South Dakota.

From a high point of 1,751 feet on the drainage divide the stream drops to an elevation of about 1,350 feet, the average Missouri River level at Soldier Creek mouth. The upper end of the drainage basin is gently rolling, grass covered land, and although there are no elevations available for other high points of the Soldier Creek basin, it is unlikely that the relief exceeds 400 feet.

Opposite the mouth of Soldier Creek, on the west side of the river, is a stream known as Good Soldier Creek (Figure 3). Fortunately, terrace relationships, and therefore the relative ages of parts of the creek, can be clearly demonstrated in Good Soldier Creek. Even more fortunately for a quantitative analysis, Good Soldier Creek represents a well integrated drainage which is developed in part on terrain similar to that underlying Soldier Creek. Good Soldier Creek is about three miles long and drops 430 feet from the high part of the drainage divide to the mouth. It flows into the Missouri River in an easterly direction in Lyman County, South Dakota. It also flows over the bedrock Pierre shale and over the well eroded moraine of the Iowan or last glacier to cross the Missouri River in this region (Flint, 1955). The eroded moraine is present high on the divide. In the lower reaches the stream flows on the post-Cary fill.

Figure 2. Soldier Creek. Foreground, abandoned site of old Fort Thompson on Mt-0; middle ground, Mt-2 and Soldier Creek outlined by trees; background, West 3 branch of Soldier Creek rising to upper reaches from Mt-2. (Courtesy of Smithsonian Institution, Missouri Basin Project.)

Both streams have cut and fill terraces which are graded to extensive, well defined terraces of the Missouri River. The Missouri terraces represent former levels of stabilization of the main stream and former effective base levels for both creeks. Briefly, the sequence of Missouri River terraces is as follows: The lowest, or flood plain terrace (Mt-0) stands 10 to 15 feet above average river level but is covered occasionally by flood waters. It is probably post-Altithermal in age. The intermediate terrace (Mt-1) stands about 35 to 45 feet above the present river level and is probably of Mankato age. The next higher terrace (Mt-2) stands about 80 to 100 feet above the river and is probably of Cary age. There are a few remnants of higher outwash contiguous with the Iowan moraine, but they are eroded and have such a small extent that no

Figure 3. Good Soldier Creek. Foreground, terraces graded to Mt-1 and lower levels; background, Mt-2 level and hills of Pierre shale. Stream branch upper right is 2nd order, the main branch foreground is 4th order. (Courtesy of the Smithsonian Institution, Missouri Basin Project.)

terrace pattern can be seen. For a more complete discussion of Missouri terraces at Fort Thompson see Coogan and Irving (1959).

In a Good Soldier Creek the levels graded to Mt-2 can be traced up the stream and its tributaries as far as some of the first order segments. The presence of these graded surfaces shows that Good Soldier Creek was a well established stream by the time the Missouri trench filled with Cary outwash to a level of about 100 feet above the present river. The presence of till no older than Iowan on the drainage divides likewise dates the establishment of the drainage net as post-Iowan according to Flint's (1955) morainal mapping.

In Soldier Creek the terrace relationships are not so clear. Soldier Creek is almost five times as long as its western relative and flows over a more varied terrain. The prominent terraces, clearly graded to post-Cary surfaces, seem to fade upstream and become increasingly more difficult to recognize. It was not possible to determine the age of Soldier Creek by its terrace pattern during the period of field work.

What then is the age of Soldier Creek? Ostensibly, Soldier Creek must be younger than Cary because it flows over Cary outwash. Unfortunately, the relationships are not so simple and there are several possibilities. The upper part of the basin, underlain by Iowan till and Pierre shale, may have begun to be eroded and drained by Soldier Creek as it cut back from the Missouri River across the Cary outwash of Mt-2; or it may have been eroded by some other master stream before what we now call Soldier Creek became established; or it may have been eroded by several streams which we can or can not now recognize as part of the Soldier Creek drainage system. Soldier Creek then may be a single stream developed in post-Cary time, or a stream composed of several other streams of varying ages, or part of a drainage developed by another stream in post-Iowan times and altered by the development of the main stem of Soldier Creek in post-Cary time. Other possibilities might also be suggested.

QUANTITATIVE TERRAIN FACTORS

A quantitative analysis including terrain factors outlined by Horton (1945) and Strahler (1954) was made for both Soldier Creek and Good Soldier Creek in order to see the problem in a different light. The Good Soldier Creek data are from the South Dakota State Geological Survey map of the Stephan Quadrangle, 15′ (Curtiss and Waddel, 1951). Soldier Creek data are from part of the Stephan Quadrangle and from part of the Lower Brule Quadrangle, 15′ (Petsch and Curtiss, 1950). These geological maps do not have a topographic base.

The composition of a drainage net may be expressed in terms of its terrain factors as described below. Horton (1945) asks the question "whether stream systems in similar terrain and which are genetically similar should not have identical or nearly identical stream composition?" He concludes in the same paragraph that they should and do.

Strahler (1954) suggests three main categories of data which may be derived directly from a map of a drainage basin. First are the linear aspects of the channel system including stream order, bifurcation ratio, stream lengths, length of overland flow, and stream pattern in terms of azimuthal relationships. Second is the areal aspect of the drainage basin including the basin area, basin shape, and drainage density. Finally, there is the relief or gradient aspect including channel gradients, slope gradients, etc. Unfortunately, lack of topographic maps of the Fort Thompson area prevents the calculation and discussion of gradient aspects.

Individual terrain factors. To obtain the data necessary for calculation, the drainage basins of both streams were traced from the maps and the area of each basin measured with a polar planimeter (Figure 4).

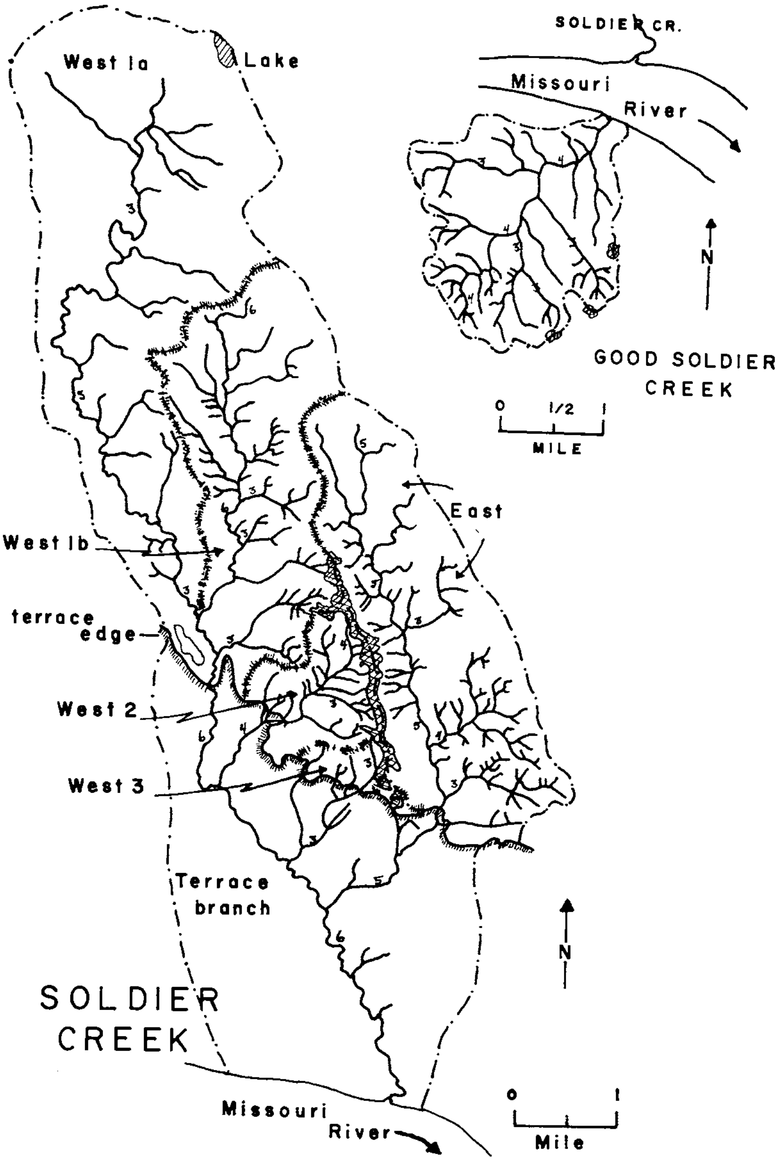

Figure 4. (Left) Soldier Creek drainage basin and subbasins. Small numbers denote stream orders. Cross hatched area between West 2 and East underlain by Iowan moraine. (Right) Good Soldier Creek drainage basin. Small numbers denote stream orders. Cross hatched area underlain by Iowan moraine.

Next the order of the stream was determined according to Horton's (1945) method in which the unbranched fingertip tributaries are designed as first order, and these only; tributaries of the second order receive branches of the first order and these only; and third order streams must receive a branch of the second order but may receive first order tributaries as well. The fourth, fifth, etc. order streams act like the third, each receiving a stream of the next lower order and orders. The main stream has the highest order.

The length of each stream branch of each order was measured. The drainage density, or average length of streams within the basin per unit of area was calculated according to Horton's formula $Dd = \frac{L}{A}$, where L is the total length of streams and A is the area. A well drained basin has a larger value for the drainage density than a poorly drained one.

The length of overland flow is equal to the reciprocal of twice the drainage density where the relief is low (Horton, 1945) and may be calculated by the formula $l_o = \frac{1}{2Dd}$. This value is a reflection of the infiltration capacity, a function of soil texture, vegetal cover, slope, lithologic composition of the bedrock, and other aspects of the terrain.

Table 1

Quantitative Terrain Factors

	Soldier Creek	Good Soldier Creek
Shape	Subrectangular-elongate	Pear shaped
Drainage area in square miles	33.3	3.72
Stream order of main stream	6	4
Stream numbers		
1st order	140	38
2nd order	49	10
3rd order	9	3
4th order	4	1
5th order	1	
6th order	1	
Total	204	52
Average stream length in miles		
1st order	.25	.26
2nd order	32	.45
3rd order	2.63	1.16
4th order	3.9	3.0
5th order	4.2	
6th order	14.3	
Bifurcation ratio	2.8	3.5
Drainage density	2.5	5.
Stream frequency	5.8	14.0
Length of overland flow in feet	10,600	4,730

Stream frequency is the number of streams per unit of area, $F_s = \frac{N}{A}$, where N is the total number of streams in a drainage basin of A areal units.

The bifurcation ratio, or ratio of number of streams of a given order to the number of streams of the next lower order is an important dimensionless feature of streams. The bifurcation ratio is determined from a plot on semilog paper of the number of stream segments of each order against the stream order. The ratio is equal to the point of intersection of the fitted straight line regression with the line representing the next to highest stream order. Horton (1945) observed that the bifurcation ratio is generally higher for hilly, well dissected drainage basins than it is for rolling, poorly dissected ones.

Discussion. A comparison of factors which comprise the drainage composition of Good Soldier Creek with those for Soldier Creek is useful in light of Horton's conclusion that stream systems developed on similar terrain and which are genetically similar have nearly identical stream composition.

Table 2

Quantitative Terrain Factors

	Soldier Creek Subbranches					
	West 1a	West 1b	West 2	West 3	East	Terrace
Shape	elongate	elongate	pear	irregular	elongate	subrectangular
Drainage area square miles	9.7	4.8	1.2	0.4	5.7	9.6
Stream order of main stream	3	4	4	3	5	4
Stream numbers						
1st order	17	32	16	5	62	8
2nd order	6	12	7	2	19	3
3rd order	1	2	1	1	3	1
4th order		1	1		1	1
5th order					1	
Total	24	47	25	8	86	13
Average stream length in miles						
1st order	.42	.16	.18	.43	.09	.24
2nd order	.68	.61	.40	.36	.32	.9
3rd order	8.4	2.03	.8	1.72	1.13	1.7
4th order		4.95	1.24		4.4	5.2
5th order					4.2	
Bifurcation ratio	2.5	3.2	2.6	2.2	2.7	2.8
Drainage density	2.0	4.1	6.5	5.1	3.9	1.1
Stream frequency	2.4	9.8	20.8	17.0	15.0	1.3
Length of overland flow in feet	13,700	6,300	4,050	10,000	4,100	22,000

Soldier Creek has a lower bifurcation ratio (2.8) than Good Soldier Creek (3.5) which suggests that Soldier Creek is a less well developed drainage even though the order of the main stream is greater (Table 1). The figures for drainage density bear this out. Whereas Good Soldier Creek has 5.5 miles of stream channel for each square mile of drainage basin, Soldier Creek has only 2.5, or about half as much. Likewise, Good Soldier Creek has a greater number of streams, 14, per square mile than has Soldier Creek with only 5.8 streams per square mile. It has been suggested that, where underlying geological structure does not determine the shape of the drainage basin, the "ideally" well drained basin approaches a pear-shaped figure. Good Soldier Creek basin is pear-shaped. Soldier Creek basin is roughly elongate and subrectangular. The conclusion that Good Soldier Creek represents a more developed and integrated drainage system than Soldier Creek is inescapable.

A comparison of the composition of Good Soldier Creek with the composition of separate parts of the Soldier Creek drainage is also useful (Table 2). Six separate subbasins of Soldier Creek were distinguished (Figure 2) and the terrain factors calculated separately for each. Although the basin designated as West 1b is not pear shaped, other factors are similar to those displayed by Good Soldier Creek. For example, West 1b and Good Soldier Creek drain approximately equal areas and each stream is of the fourth order. The bifurcation ratio of West 1b approaches that of Good Soldier Creek more closely (3.2 to 3.5) than any of the others. The drainage density for West 1b is not as high (4.1) as that for Good Soldier Creek (5.5) but approaches it. Stream frequency and length of overland flow are comparable. Again, if we accept Horton's conclusion, we may entertain the suggestion that the West 1b branch of Soldier Creek, which has a stream composition similar to Good Soldier Creek and which is developed on similar terrain, is indeed of similar origin.

The development of the lower part of Soldier Creek on the terrace illustrates a significantly different situation. Although when taken alone the terrace subbasin of Soldier Creek is more than twice as large as the Good Soldier Creek basin, the order of the highest stream is the same, only 4. The bifurcation ratio is appropriately smaller (2.8), suggesting a less well developed drainage for the terrace subbranch. There are only 1.1 miles of stream channel per square mile and only 1.3 streams per square mile on the terrace. The rather undefinable limit of the terrace subbasin is perhaps a factor in the strong dissimilarity, but even a casual observer could not fail to notice that the terrace is poorly drained by Soldier Creek.

One may conclude that on the terrace Soldier Creek either flows on terrain different from that underlying Good Soldier Creek, or that the creeks are genetically dissimilar, or both. The same is true for the terrace and West lb subbranches of Soldier Creek.

Internal inconsistencies in the figures for various terrain factors of several of the subbasins are apparent (Table 2). For instance, subbranch West 3 which has a low bifurcation ratio has a fairly high drainage density and stream frequency. It should be realized, however, that the recognition of once genetically different, but now unified subbasins, is masked by the more recent history of the stream. It may be that values for terrain factors from an anomalous drainage basin may not be significant except that they show an anomalous and inconsistent pattern.

Summary. A simple quantitative terrain analysis from available maps shows that different parts of Soldier Creek are of different ages or are developed on different types of terrain. Unfortunately, the method does not single out the correct possibility. What then is the age of Soldier Creek? More information, field evidence in particular, is needed.

SUPPORTING GEOLOGICAL INFORMATION

The top three members of the Pierre shale are exposed in the Fort Thompson area. They are composed of gray gumbo clay, bentonitic clay and bentonite, minor gray marl, and foraminiferal chalk. These rocks support vegetation ranging from short grass prairie to almost bare ground. In fact, some beds characteristically have no vegetal cover. The infiltration capacity of the clayey bentonitic beds is very low and runoff is correspondingly high. In this part of South Dakota the precipitation averages 16 inches a year, four-fifths of which occurs in the form of summer showers. Ranchers have adjusted to these conditions and dammed many of the creeks which flow on the Pierre shale so the region is dotted with stock ponds.

In sharp contrast to the composition of the Pierre shale, the material which makes up the fill of Mt-2 at Fort Thompson ranges from fine sand to medium gravel. It is outwash composed largely of granitic fragments with a thin cover of wind blown silt and has a high infiltration rate. Mt-2 fill stores considerable water. Seeps and springs are present along the base of the terrace at the contact of the fill of Mt-2 and the buried shale bedrock and a good water supply comes from a well at the U. S. Government Indian School two miles north of Fort Thompson on the terrace.

The larger infiltration capacity of the outwash of Mt-2 is expressed in terms of terrain factors by a greater "length of overland flow," a smaller number of miles of stream channel per unit area, and a smaller bifurcation ratio. If there are no undrained areas developed on the terrace, and if both terrace and area underlain by Pierre shale receive the same amount of rain, then both areas must be equally well drained. Parenthetically, it should be noted that a few ponds do develop on Mt-2 in wet years where colluvial, clayey Pierre shale has been washed onto the back of the terrace. But on most of the terrace the drainage largely takes place through the terrace fill to springs or by rapid evaporation from ponds after rainfall. The almost flat surface of the terrace hinders runoff and there is little drainage by runoff directly into the stream channels. In the upper reaches of Soldier Creek and in most of Good Soldier Creek, underlain by shale, the runoff is fairly rapid and little water is stored except in artificial stock ponds.

Terrace studies in the Fort Thompson area show that the Missouri River has occupied its present southerly channel since the deposition of the fill of Mt-2. Previously, the river channel was as far north as the edge of the terrace shown on Figure 4. At that time the main stream of Good Soldier Creek could have been as much as six or more miles long, twice its present length, whereas the post-Iowan streams on the left bank, which were eroding the Iowan till and underlying Pierre shale, would have had their mouths at what is now the back or northerly edge of Mt-2. They were then similar to the dozens of small short creeks which presently drain the left bank of the Missouri just south of Crow Creek, or the right bank of the Missouri between Good Soldier Creek and Counselor Creek.

History of Soldier Creek

Terrace studies and morainal maps show that Good Soldier Creek is a post-Iowan stream which was reasonably well developed by the time the Missouri River deposited the Cary outwash fill of Mt-2. Soldier Creek, we have seen, is a stream developed on varied terrain with segments of varied origin. A tentative history of Soldier Creek, based on field evidence and a consideration of a simple terrain analysis, follows.

With the retreat of the Iowan glacier small rivulets began to drain and incise the till covered Pierre shale. The mouths of those creeks were located at the northerly edge of the present Mt-2, or if located farther south were on terrain since removed by the river or covered by Mt-2 fill. After the deposition of Mt-2 outwash the river changed its channel to a more southerly position. A set of new rivulets developed on the edge of Mt-2 which was undergoing incision by the Missouri River down to at least the level of Mt-1, a drop of at least 40 feet. One of these rivulets (Soldier Creek) cut back and eventually captured the various older post-Iowan streams which were still draining the area underlain by Pierre shale.

The northerly part of Mt-2, opposite and in a line with the northwesterly branches of Soldier Creek (West la, lb, and 2), has a deposit at the top of the fill of more than 8 feet of clay. It is boggy during wet seasons, but at present does not receive enough water to form a pond. A lake may have occupied this 5 mile square area after the Missouri switched to its present southerly channel but before Soldier Creek captured the older stream segments by headward erosion.

In summary, Soldier Creek consists of several branches of at least two different ages. The terrace branch has surfaces graded to Mt-1 and Mt-0 which were devloped as the stream cut down in response to large scale fluctuations of the Missouri River as it incised the Cary outwash of Mt-2. The main trunk of Soldier Creek then is post-Cary in age and developed after the southerly switch of the Missouri channel. The upper reaches, including subbranches West 1, 2, 3 and East, contain no terraces obviously graded to the Mt-2 level and are post-Iowan streams captured by the headward erosion of the main post-Cary terrace branch. The terrace branch combined the upper subbranches and itself into the composite stream with an anomalous pattern which we now call Soldier Creek.

CONCLUSION

The age of Soldier Creek is an interesting but not very significant geomorphological problem. Its solution, however, does call attention again to the availability of a simple physiographic technique which can focus thought on the parts of the problem to which field evidence fruitfully can be applied. Use of a quantitative terrain analysis *together* with evidence normally gathered in the study of Pleistocene problems can yield answers to questions which seem otherwise unsolvable, and indeed, can yield answers which are indispensable to a complete understanding of a sequence of Pleistocene events and to its interpretation as historical geology.

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