TORS ON THE EAST AND WEST SUMMITS OF THE BEARTOOTH PLATEAU: AN INVESTIGATION INTO POSSIBLE STRUCTURAL CONTROL BY FRACTURING.

Mark A. Hespenheide
Department of Geology
Pomona College
Claremont, CA 91711

Introduction to the Historical Conflicts on the Origins of Tors

A tor is a remnant landform created in the periglacial regime in which the removal of weathered material leaves behind an isolated, discrete body of the bedrock standing above the surrounding surface. Throughout the history of their description there has been a great deal of controversy about their origins. The two models proposed are the single-cycle model and the two-cycle model. Under the single-stage model, the tor is weathered out at the same time that the detrital material is being removed. Under the two-stage model, the incipient tor is first created through chemical weathering while still sub-surface and then later exhumed. It was theorized that single-cycle tors should develop angular blocks or fragments whereas two-cycle tors should develop rounded constituent blocks. Under both models, the final result of the origin is a stacked pile of bare rock, either rounded or angular, that stands above a surrounding cryoplanation surface. The structural geology of the regolith enters into the consideration of the origin of tors through the exploitation of joints or other planes of weakness. These joints or fracture planes should influence the development of the tor whether they act as access routes for chemical weathering or as planes of weakness for later frost action. However, some general assumptions made about the implications of certain tor features seem inconclusive or incorrect. Derbyshire's (1972) work in Victoria Land, Antarctica shows that the rounded or angular nature of tor blocks varies within even a relatively small area and even among tors of identical composition. Neither does it appear possible to assign all the tors in one locality to either one model or the other; Caine (1968) determined that both processes are partially correct for modeling the origin of tors on Ben Lomond, Tasmania. Since investigations proposed by Derbyshire to determine the specific type of tor-origin model are outside the scope of a Keck project and since the concept of structural controls by jointing on tors had not been called into question since the relatively recent works by Derbyshire and Caine, it seemed important to investigate the possibility of structural controls on the occurrence and possibly on the size and shape of the tors on the East- and West Summits of the Beartooth Plateau.

Field Methods

Over a three week period in August of 1994, I collected over two hundred planar orientations in the tor areas and over twenty-three hundred spacings between joints or fracture planes in both tor and non-tor areas. Because the erosion surface of the Beartooth plateau affords little outcrop of the non-tor interval, fracture spacings measured in roadcuts were taken as representative of the fracture spacings in the non-tor interval. Spacings were measured using a meter stick or ten-meter tape measure and orientations of joint planes were measured using an azimuthal Brunton compass.

While standard methodology for counting the frequency of joint spacings involves counting the number of joints contained within an inscribed circle, the varying surfaces of a tor made this method functionally impossible. Instead, I chose at random a horizontal line across the face of the tor and measured the linear distance between joints or spacings. I repeated this procedure along a vertical line through the axis of greatest vertical relief. Along each of the lines fractures or spacings are recorded only if they intercept the trace at less than a 45° angle. Once the average horizontal linear fracture density and the average vertical linear fracture density are found, they can be multiplied to establish a representation of the areal fracture density of the rock. Within tor areas, horizontal linear fracture densities can be measured perpendicular to each other in order to establish a volumetric fracture density.

131- 133 years old. This date takes into account the age of the oldest tree on the deposit surface (123 years) and an 8- 10 year colonization time (Meyer, 1994).

Using this information, stratigraphic controls, and field descriptions a possible sequence of events was established. One of the greenish-gray deposits, labeled DB2 in this study, is the oldest deposit and represents the first debris flow out of those studied to occur in the Index Creek drainage. Another greenish-gray deposit, DB4, most likely represents this same event. The two brown deposits were also likely formed in one event, a debris flow occurring at least 320 years ago. In one area this deposit overlies DB2 along a distinct planar contact. Next, DB1, another greenish-gray deposit, was deposited by a debris flow at least 236 years ago and the last greenish-gray deposit, DB5, is probably from the same flow. After this the Clarks Fork river was dammed 131 to 133 years ago by the gray debris flow, DB3. The youngest dated event is recorded by a deposit 53 years old. The deposit lies exposed on the surface above the two brown deposits and is too eroded to be studied. It was dated using a scar in a tree growing on the surface of the brown deposits and partially buried by this younger deposit. The hyperconcentrated flow deposits were not dated but lie stratigraphically above DB1 and are assumed to be as recent or more recent than the 53 year old deposit because of their position within the channel. So, there are most likely 4 debris flows and 3 hyperconcentrated flows, or 5 debris flows and 2 hyperconcentrated flows, represented by deposits in the Index Creek drainage. Since an absolute minimum of 320 years ago there have been at least 3 debris flows of a magnitude great enough not to have been eroded away.

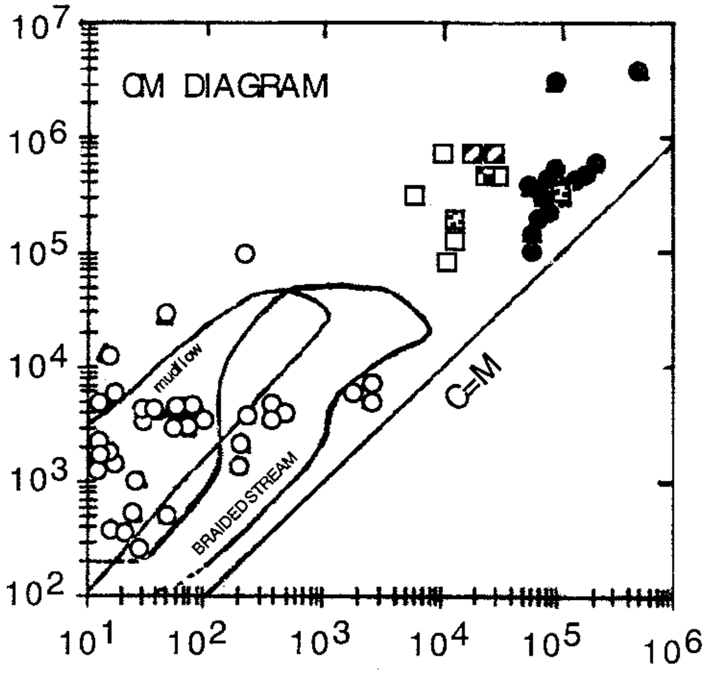

Fig. 1 CM diagram was used by Bull (1972) to determine depositional processes of alluvial fan sediments and is commonly used to distinguish between traction fluvial and debris flow modes of deposition (Kochel and Johnson, 1984). Open and solid circles represent fine and coarse portions respectively of sediments from debris fan deposits and floodplain deposits in central Virginia (Kochel and Johnson, 1984). Kochel and Johnson's data and the mudflow and braided stream envelopes of Bull (1972) are plotted here for comparison. Data for this study was taken from particle-size analyses of the entire samples, fine and coarse portions of deposits. □- greenish- gray diamicton. ▣- gray diamicton. ▨ - brown diamicton. ▦ - stratified gravels.

relative ratio of joint spacings between the tor and the immediate adjacent rock. If this is the case, this boundary should determine both the size and the shape of the individual tors.

At this point, it does not appear as if there is any correlation between fracture orientation and occurrence or the shape of tors. When looking at the tors of the Beartooth Plateau as a whole, there does not seem to be any compelling set of fractures that might exert a control on their occurrence.

Although work continues to try to establish a relationship between the lithology of the tors and their structure, it does not appear as if there is a simple correlation between lithology and fracture spacing. A preliminary thin-section analysis shows a relative lack of clay mineralization of feldspars. This evidence in combination with the angular nature of the Beartooth Plateau tors may be sufficient to establish them as single-cycle tors.

References

Bloom, A. L. 1991. Geomorphology: A Systematic Analysis of Late Cenozoic Landforms. Prentice Hall, Englewood Cliffs, New Jersey, pp.273-276.

Caine, N. 1968. The Tors of Ben Lomond: *Zeitschrift Geomorphologie*, v.11, no.4, pp.418-429.

Cheeney, R. F. 1983. Statistical Methods in Geology. George Allen and Unwin Press, Boston, Massachusetts, 165p.

Davies, J. L. 1969. Landforms of Cold Climates. The Australian National University Press, Canberra, Australia, pp.47-49.

Derbyshire, E. 1972. "Tors, Rock Weathering and Climate in Southern Victoria Land, Antarctica", *Institute of British Geography Special Publication* 5, pp.93-105.

Figure 1.a: Percent Frequency of Spacings in Tors and Non-Tor Areas

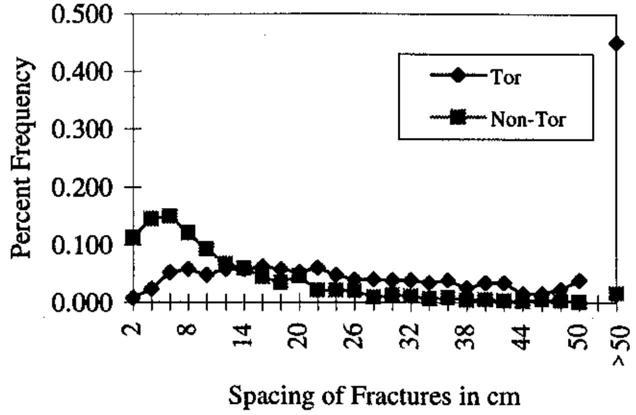

Figure 1.b: Percent Frequency of Spacings in Tors and Non-Tor Areas

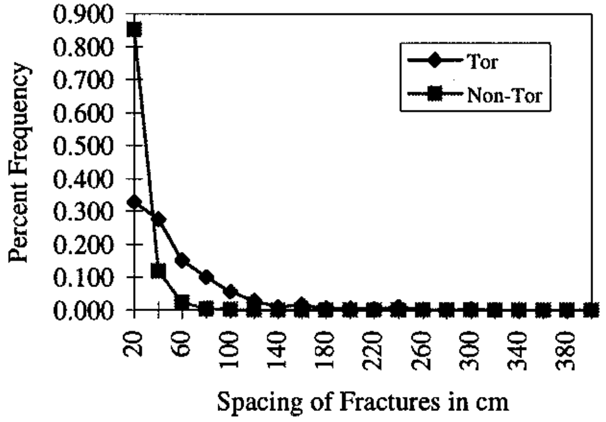

Table 1

	tor					inter-tor						
	granite	granite	mafic	mafic	all	granite	granite	mafic	mafic	basaltic?	basaltic?	all
	x-y	z	x-y	z	all	x-y	z	x-y	z	x-y	z	all
End Cell Number	643	110	123	25	643	1237	57	74	*N/A*	130	22	1237
Average	50.4	64.1	22.4	21.9	47.7	11.5	22.4	20.7		12.1	19.6	12.4
StDev(1)	48.6	60.4	19.3	19.1	48.4	12.6	13.4	15.2		12.4	10.8	13.0
StDev(P)	48.6	60.1	19.2	18.6	48.4	12.5	13.2	15.0		12.3	10.5	13.0
Variance	2364.6	3652.6	371.4	365.2	2340.6	157.6	178.8	229.8		152.7	116.9	168.2
Skew	2.4	1.6	1.8	2.6	2.4	6.1	1.6	0.6		4.0	0.1	5.0
Kurtosis	8.2	2.7	3.1	9.1	7.9	79.0	4.4	-0.7		22.3	-1.0	57.8
N	637	104	117	19	877	1231	51	68		124	16	1490
Confidence, .05	3.8	11.6	3.5	8.4	3.2	0.7	3.6	3.6		2.2	5.1	0.7
Confidence, .01	5.0	15.2	4.6	11.0	4.2	0.9	4.8	4.7		2.8	6.7	0.9

	granite:	mafic:	granite:	basaltic:
2-D fracture spacing:	3235.6	490.7	256.8	237.3

total N spacings 2367