The Utility of joints in interpreting the geologic history of the Tertiary rocks of the Crawfish Lake Quadrangle

Kyle McClure
Department of Geology, Pomona College, 609 N. College Ave. Claremont CA 91711
Faculty Sponsor: Richard W. Hazlett, Pomona College

INTRODUCTION

This paper will address the importance of joint structures of three different varieties (columnar, platy, and possible tectonic) in interpreting the geological history of a suite of volcanic rocks in the Crawfish Lake Quadrangle of the Blue Mountains Physiographic Province in Northeastern Oregon. It will provide detailed descriptions of the joint patterns. It will describe where each type was found within the section and what possible interpretive ramifications their presence might have. And it will attempt to answer the following questions:

1. Has tectonic deformation taken place in the Crawfish Lake Quadrangle?
2. To what extent can we practically use strike-dip measurements on joints to determine the structure of volcanic rocks?

These questions are significant because *if* we are able to record any type of tectonic deformation in the volcanics of the Crawfish Lake Quadrangle, then this deformation would represent the most recent in the Blue Mountains, and would therefore also be present in the basement rocks, and would need to be taken into consideration when trying to reconstruct the older deformational histories of these rocks.

COLUMNAR AND PLATY JOINTS

Many volcanic rocks, especially basaltic lava flows are divided into slender polygonal columns of the type that will be familiar to anyone who has spent time driving the highways of the American Northwest as they are quite prominent in the Columbia River Basalts (CRB) that cover much of this region. These columns are known as columnar joints (figure 1).

The regular, distinctive geometry of columnar joints led early observers to the conclusion that they were created by supernatural beings, as indicated by the names of sites such as the Devils Postpile in California, the Devils Tower in Wyoming and the Giant's Causeway in Northern Ireland. Educated ideas about the origins of columnar joints began in the late 17th century with the publication of papers on the Giant's Causeway. The ideas in these papers, though more scientific then the previous supernatural explanations, were still largely speculative and were highly influenced by moral and religious considerations (Aydin and Degraff 1988). It was nearly two centuries before the development of the now accepted concept that these joints are the product of contraction during the cooling of lava (Mallet 1875). More recently, it has been shown that columnar joints initiate at the surfaces of cooling lava flows and grow inward as cooling proceeds. Joint growth occurs incrementally, producing joint segments whose surface markings indicate both the vertical sequence of segment formation, as well as the local and overall directions of joint growth (Degraff and Aydin 1987).

Large amounts of columnar jointing can be found in the volcanic rocks of the Crawfish Lake Quadrangle, primarily in the Chicken Hill Dacite and the aphyric basalt units. Prominent outcrops of dacitic columnar jointing run along the Chicken Hill Ridge. Basaltic columnar joints also make up the large knob just south of the Chicken Hill summit, as well as the top of Black Butte. The columnar jointing of the Crawfish Lake Quadrangle can be classified as falling into two separate categories. The first is the spectacular jointing which is found in the basaltic units. This type of jointing is very well preserved, having suffered little from the effects of weathering, and shows textbook examples of polygonal columns radiating away from past cooling surfaces. The second type of columnar joint found in the Crawfish Lake Quadrangle is the type that is composed of the dacites of Chicken Hill. This type of columnar jointing is nowhere near as well preserved as the first type. These joints have undergone severe weathering, and are rougher and blockier then the joints found in the basalts.

Important to this paper is the fact that columnar joints form perpendicular to the surface upon which the cooling lava is resting. This fact has a large impact on the interpretation of lava flow sequences and on the investigation of tectonic activity, especially in the Crawfish Lake Quadrangle.

Platy joints are also present in the volcanic rocks of the Crawfish Lake Quadrangle. Unlike columnar joints, platy joints are not caused directly by the cooling actions of a lava flow, but rather are caused by the effects of weathering on the incremental growth bands of columnar joints. Platy joints then, are created by the actions of wind and rain over a period of time, and are therefore likely to be found in older, more beat up rocks. This is the case in the Crawfish Lake volcanics where platy joints are found only in the Chicken Hill dacites, and not in the younger basalts.

Both field studies and experiments show that columnar joints begin at the boundaries of magma bodies and grow inward as the magma cools and solidifies (Degraff and Aydin 1987). Thermal models of magma bodies and field studies in Hawaiian lava lakes show that cooling, solidification and build up of thermal stress spread gradually from the boundaries (Peck 1978). That this growth occurs incrementally is inferred primarily from joint surface morphology. That is, columns exhibit parallel discontinuous bands defined by textural and geometric variations, which are arranged normal to column axes (figure 2).

These platy joints are of course not actually "platy" until they have been made so by the effects of erosion. When they first come into existence they are nothing more than slight variations in the morphology of a larger columnar joint. But when subjected to million of years of erosion these small variations are exploited, and are eventually fractured off, creating the platy structures found in the dacitic volcanic rocks of the Crawfish Lake Quadrangle.

Platy joints are significant because they form normal to axes of columnar jointing. Since columnar joints form perpendicular to the surface upon which the lava is cooling, and since platy joints form perpendicular to the axes of the columnar joints, we are able to use platy joints to provide a rough estimation of the orientation of the original surface upon which the lava was deposited, of the lava's "bedding plain."

FIELD WORK

The relationship between columnar and platy jointing was significant to our mapping and to our interpretation of the volcanic units of the Crawfish Lake Quadrangle. We used these two types of joints, whenever we found them together in a single outcrop to determine a rough bedding plane orientation for that outcrop. We would do this by measuring the strike and dip of several platy joint planes in the outcrop where it was obvious that they were oriented normal to a columnar joint axis. All of the strikes and dips on our map were obtained in this way. In order to expand upon this mapping method, I undertook a smaller, more localized, mapping project of my own. I mapped a 40m by 15m section of a dacite flow making up the top of Chicken Hill. The area mapped included 150 square meters of large, blocky columnar joints along the north face of the ridge, and 150 square meters of corresponding platy joints along the south face of the ridge (figure 3). I obtained orientation data for each of these joints every 1meter. In doing this I hoped to find a clear association between the orientations of the two types of joints, showing that platy joints do indeed regularly form perpendicular to the axes of columnar joints. By proving that such an association actually does exist, not only in theory, but also in the practicality required by work in the field, taking into account erosion and other such factors, it would enable a greater degree of accuracy in lava flow mapping to be possible. In our mapping we were reluctant to assign orientation values to flows where we found platy joints, but no columnar joints. A greater certainty about the true relationship between columnar and platy joints would have allowed us to characterize these sites.

I have yet to do the statistical analysis on the data obtained in this mapping experiment. However, I present rough results below: (I use the terms "strike" and "dip" for the platy joints, because in mapping we used these joints to represent bedding planes)

Platy joints	
Average Strike	North 78.09 East
Average Dip	55.48 South
Columnar joints	
Average Trend	North 63.76 East
Average plunge	43.23 North

Table 1: Average orientations of platy and columnar joints

DISCUSSION

As can be seen, the difference in the dip of the platy joints and the plunge of the columnar joints is 82 degrees. This is very close to the expected 90-degree difference. There is a 15-degree difference between the strike of the platy joints and the trend of the columnar joints. Also, close to the expected result (that the strike and trend would be identical). Do these results, though, indicate that we can use platy joints as indicators for bedding plane orientations when they are not found in conjunction with columnar joints? We cannot do so with confidence. What this study shows is that both columnar joints and platy joints are useful indicators of flow orientation when used together, however when either is removed from a site, there is simply too much room for error to draw any meaningful conclusions. Even when both types of joints are found together, there is plenty of potential for error. Here we have an area with prominent, obvious columnar jointing in clear association with large amounts of platy jointing and we still end up with error margins of 8 and 15 degrees. Unfortunately, this is the only method presently available for determining bedding plane orientations in lava flows whose contacts are not exposed or are only poorly exposed. We are, therefore, handicapped when we attempt to characterize tectonic activity in regions composed primarily of volcanics, if only because we lack appropriate tools to accurately determine whether or not deformation has taken place, for the strikes and dips we generate can only ever be rough approximations.

Another source of confusion often encountered when one is trying to piece together a tectonic history for volcanic rocks is created by the topography of the land over which the volcanic rocks were deposited. Unlike sedimentary rocks, volcanics can be, and often are, deposited on topography which is quite varied. When lavas flow over terrain with topographic relief, they fill in valleys, accumulate in basins, and thinly top ridges. This is exactly what happened in the Crawfish Lake Quadrangle, with the large basin just to the north west of the quadrangle filling in to great thickness with volcanics and related sedimentary rocks. When dacites and basalts are deposited on such a landscape the results are sets of joints that, at first, look as if they were created by large scale tectonic activity, but which, in reality, are nothing more than a function of the way that lavas cool from the outside in, breaking into columnar joints (figure 4).There are several volcanic outcrops in the Crawfish Lake Quadrangle which exhibit the spectacular effects of this cooling process. Among these are the top of Black Butte and, "Johnny's Spot."

TECTONIC JOINTS

The above-described columnar and platy joints are not the only types of joints found in rocks. If a rock is brittle, or if forces are exerted on it faster than it is able to bend to accommodate the strain, the rock fractures. Usually when this occurs there is some measure of displacement between the fracture surfaces, creating a fault. If essentially no displacement occurs, the resulting crack is a tectonic joint. Most rock at or near the surface is brittle, and nearly all exposed bedrock is jointed to some extent. There are two types of stresses that will create tectonic jointing; compressional and tensional forces. Compressional stress produces two joint sets (a joint set is a family of joints produced from a common origin) that cut across each other and intersect the direction of stress. Tensional stress produces a single joint set perpendicular to the direction of stress.

Tectonic joints can be used to infer quite a bit about the geologic history of rocks in which they are found. On a basic level, they tell you whether or not those rocks have experienced tectonic stress, and they tell you what types of stresses those were. Many tectonic joints, especially those that cut through rocks of different lithologies, have their sources in folds produced by regional deformation.

FIELD WORK

In our mapping of the volcanic rocks of the Crawfish Lake Quadrangle we came across several outcrops in which there appeared to be such tectonic joints cutting across the platy joints and the columnar joints mostly in the Chicken Hill dacites. We were able to identify these possibly tectonic joints primarily because of the fact that they were oriented in such a way that they did not appear to be either of the other two types of joints we had already been working with. In some places they were actually oriented parallel to the axis of the columnar joint through which they were cutting. These possible joints were found in the area surrounding the summit of Chicken Hill.

DISCUSSION

We took orientation readings on all possibly tectonic joints that we found in hopes that we would be able to piece together a picture of a possible stress field, indicating some kind of tectonic activity. Unfortunately, the readings produced no indication of the actions of tectonic forces. Rather, they were randomly distributed, containing no pattern whatsoever. All that we can say with certainty about these joints is that they exist in the Chicken Hill Quadrangle and that they do not appear to be columnar or platy. Therefore, we assign them a tentative designation as being possibly tectonic, but we do so reluctantly, having seen no other indications of tectonic activity in this area in the time since the Oligocene; no folding (that cannot be explained using the lava on a varied landscape model), and no faulting. Thus the deformational history revealed in the Tertiary volcanic rocks of the Crawfish Lake Quadrangle is, for the most part, nonexistent.

REFERENCES

Aydin, A. and Degraff, J., 1988 Evolution of Polygonal Fracture patterns in Lava Flows: Science v. 239 p. 471-476

Degraff, J. M. and Aydin, A. 1987 Surface Morphology of columnar joints and its significance to Mechanics and direction of growth: Geological Society of America, v. 99, p.. 605-617

Eyles, Arnaud, Scheidegger Adrion, Eyles, 1997 Bedrock jointing and Geomorphology: Geomorphology v.

19 n. 1-2 p. 17-34

Francis, P., 1976 Volcanoes: Penguin Books ltd. p. 104-114

Hobbes, B. and Means, W. D. and Williams, P. F. 1976 An Outline of Structural Geology: John Wiley and Sons Inc. p. 289-300

Orr, E. and Orr, M. and Ewart, E. M., 1992 Geology of Oregon 4th edition: Kendall Hunt Publishing Co. p 21-50

Plummer and McGreary 1985 Physical Geology: William C Brown Publishers p. 299

Pollard, D.D. and Aydin, A., 1988 Progress in understanding jointing over the past century: Geological Society of America Bulletin, v.100, p. 1181-1204

Ramsey, R. G., 1976 International Series in the Earth and planetary Sciences- Folding and Fracturing of Rocks: McGraw Hill Book Company p. 91, 113

Walker, G., 1990 Miocene and Younger Rocks of the Blue Mountains Region, Exclusive of the Columbia River Basalt Group and Associated Mafic Lava flows: US Geological Survey Professional Paper 1437

Walker, G. and Robinson, P. T., 1990 Cenozoic Tectonism and Volcanism of the Blue Mountains Region: US Geological Survey Professional Paper 1437

Walters and Aldrich, 1997 Distinguishing Cooling and Tectonic Joints: Geological Society of America, 1997 Annual Meeting Abstracts with Programs, v. 29 n. 6 p. 417

Younes, and Amgad 1996, Tectonic implications from joints: Geological Society of America Abstracts with programs, v. 28 n. 3 p. 110

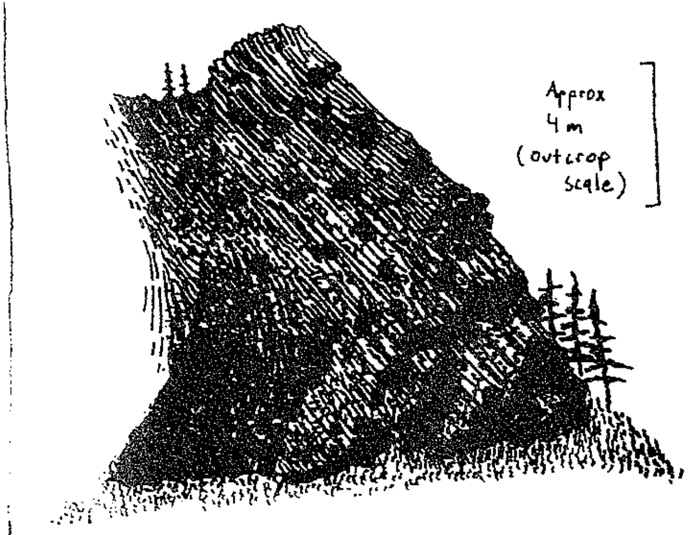

Figure 1: An outcrop displaying spectacular columnar jointing

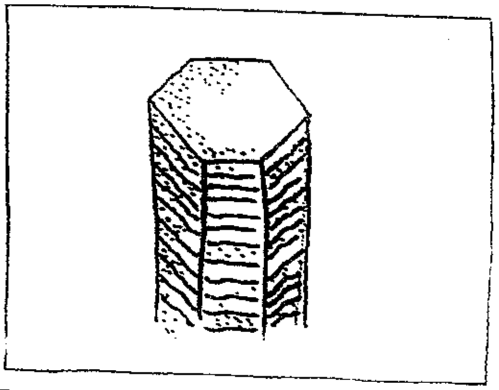

Figure 2: A columnar joint displaying growth banding which later weathers into platy jointing

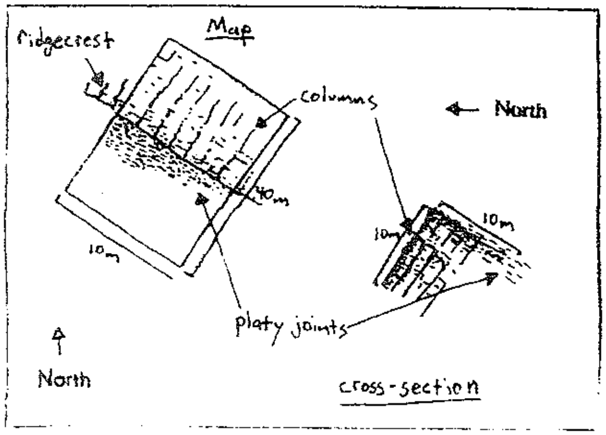

Figure 3: The map project

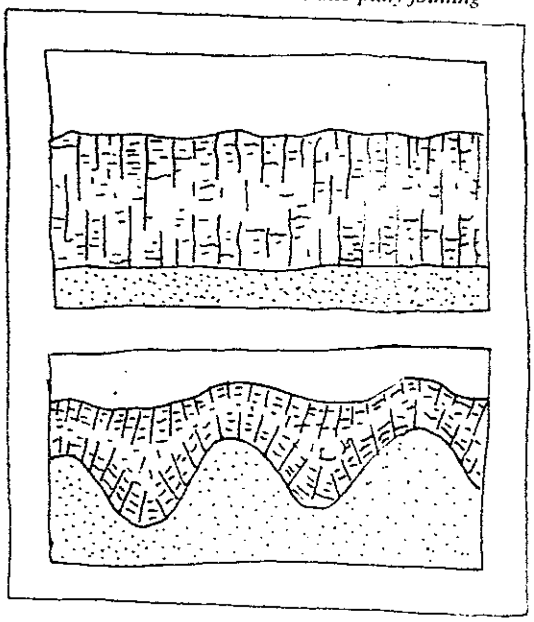

Figure 4: Columnar joint formation on regular and varied terrain