Bull Volcanol (1986) 48: 189-194

Bulletin of Volcanology

Internal structural variations in a debris-avalanche deposit from ancestral Mount Shasta, California, USA

Tadahide UI[1]* and Harry Glicken[2]

[1] US Geological Survey, 345 Middlefield Road MS910, Menlo Park, California 94025, USA
[2] DA Johnston Cascades Volcano Observatory, US Geological Survey, 5400 MacArthur Boulevard, Vancouver, WA 98661, USA

Abstract. Various parameters of the internal structure of a debris-avalanche deposit from ancestral Mount Shasta (size and percentage of block facies in each exposure, number and width of jigsaw cracks, and number of rounded clasts in matrix facies) were measured in order to study flow and emplacement mechanisms. Three types of coherent blocks were identified: blocks of massive or brecciated lava flows or domes, blocks of layered volcaniclastic deposits, and blocks of accidental material, typically from sedimentary units underlying Shasta Valley. The mean maximum dimension of the three largest blocks of layered volcaniclastic material is 220 m, and that of the lava blocks, 110 m. This difference may reflect plastic deformation of blocks of layered volcaniclastic material; blocks of massive or brecciated volcanic rock deformated brittly and may have split into several smaller blocks. The blocks in the deposit are one order of magnitude larger, and the height of collapse 1100 m higher, than the Pungarehu debris-avalanche deposit at Mount Egmont, New Zealand, although the degree of fracturing is about the same.This suggests either that the Shasta source material was less broken, or that the intensity of any accompanying explosion was smaller at ancestral Mount Shasta. The Shasta debris-avalanche deposit covered the floor of a closed basin; the flanks of the basin may have retarded the opening of jigsaw cracks and the formation of stretched and deformed blocks such as those of the Pungarehu debris-avalanche deposit.

Introduction

Crandell et al. (1984) described the internal structure of a debris-avalanche deposit (hereafter referred to as the Shasta deposit) in Shasta Valley, California, that was derived from a volcano ancestral to Mount Shasta about 300 000–360 000 years ago. They identified two discrete facies of the deposit, a block facies and a matrix facies.

The block facies consists mainly of relatively coherent pieces of the source volcano (blocks) that make up scattered mounds, hills, and ridges. The hills decrease in number, basal area, and height towards the distal end of the deposit. The blocks include fragments of andesitic breccia and coherent volcaniclastic deposits, many of which are cut by steep normal faults. The blocks range from tens to hundreds of meters across. Some blocks show evidence of rotation about a vertical axis, but such blocks remained right side up.

The matrix facies locally veneers the slopes of hills formed by the block facies and underlies flat areas between the hills. The matrix facies is a blended, unsorted, and unstratified mixture of material ranging in size from clay to boulders and texturally similar to a lahar. Ui et al. (1986a) restricted the usage of the term "matrix facies" only to areas of the blended deposit of mappable size. The term "matrix" (without "facies") was used for blended parts of the deposit too small to be mapped. To avoid confusion with the sedimentological definition of matrix, and to be consistent with Crandell et al. (1984), "matrix facies" is defined in this paper to include all blended parts of the deposit.

Many clasts in the matrix facies are lithologically identical to andesite fragments of the block facies. The matrix facies also includes clasts of sandstone and conglomerate derived from rocks underlying Shasta Valley. Crandell et al. (1984) assumed that the debris-avalanche became progressively more fragmented during movement. They also suggested that the mobility on the debris-avalanche was enhanced by fine-grained material incorporated from water-saturated sediments on the flat floor of Shasta Valley.

The deposit extends within Shasta Valley from 15 to 55 km northwestward from the top of present Mount Shasta. According to typical relations between maximum collapse height and maximum runout distance in debris-avalanches (Ui 1983; Ui et al. 1986b), the ancestral Mount Shasta volcano just before the debris avalanche probably was about

Offprint requests to: T Ui

* *Present address:* Department of Earth Sciences, Faculty of Science, Kobe University, Nada, Kobe 657 Japan

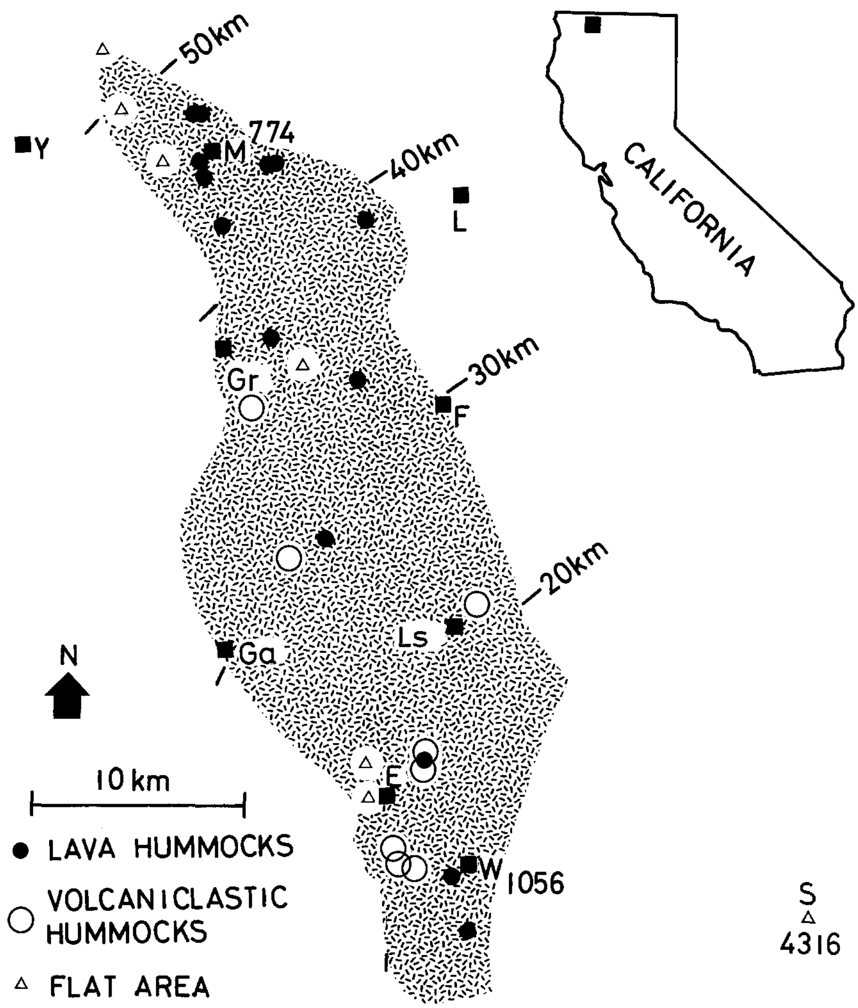

Fig. 1. Location map. The hatched area shows the approximate extent of the debris-avalanche deposit from ancestral Mount Shasta (after Crandell et al. 1984). *S:* assumed source of debris-avalanche at an altitude of about 4300 m. *W:* Weed; *E:* Edgewood; *Ls:* Lake Shastina; *Ga:* Gazelle; *Gr:* Grenada; *F:* Four Corners; *L:* Little Shasta; *M:* Montague; *Y:* Yreka. Elevations are shown at Weed and Monatgue. Distances are indicated in kilometers from the assumed source. Measured sites are classified as (1) exposures of hummocks where andesite blocks predominate, (2) exposures of hummocks where volcaniclastic blocks predominate, and (3) exposures of flat areas between hummocks, where matrix facies predominates

the same height as the present Mount Shasta. Thus, the maximum height for the source of the debris-avalanche is assumed to be at approximately 4300 m above sea level, the elevation of the summit of present Mount Shasta. The surface elevation of the deposit is 1060 m near the base of the volcano at Weed and 770 m near its distal end at Montague (Fig. 1).

The same parameters measured for the Pungarehu debris-avalanche deposit of Mount Egmont, New Zealand (hereafter referred to as the Egmont deposit) (Ui et al. 1986a) were measured for the Shasta deposit. The number of rounded clasts within the matrix facies was also estimated. The purpose of this study is to analyze flow and emplacement mechanisms of the Shasta deposit and to determine whether features observed in the Egmont deposit also occur in the Shasta deposit.

The methods of measurement were the same for both deposits, but the quality of exposures differs. Many roadcuts as wide as 50 m expose hummocks in the Egmont deposit, but big quarry exposures are sparse. Exposures of the matrix facies in flat areas are also sparse in the Egmont deposit except along coastal cliffs. There are fewer exposures of the Shasta deposit overall but more large quarry exposures; many gullies form excellent exposures in flat areas.

Internal structures were observed and parameters measured at 28 exposures in Shasta Valley (Fig. 1). Of these, 14 are exposures of the block facies, consisting of dense massive andesite, probably derived from parts of lava domes or thick lava flows ("lava hummocks" in Fig. 1). Eight of the exposures are in the block facies where it consists of stratified, poorly-consolidated volcaniclastic deposits (Fig. 2a and "volcaniclastic hummocks" in Fig. 1). The remaining six exposures are in flat areas and consist primarily of matrix facies ("flat area" in Fig. 1).

Variation of block size and facies in exposures

The block facies of the Shasta deposit is divided into three types, based on the nature of material: (1) massive or brecciated andesite derived from lava flows or domes (lava

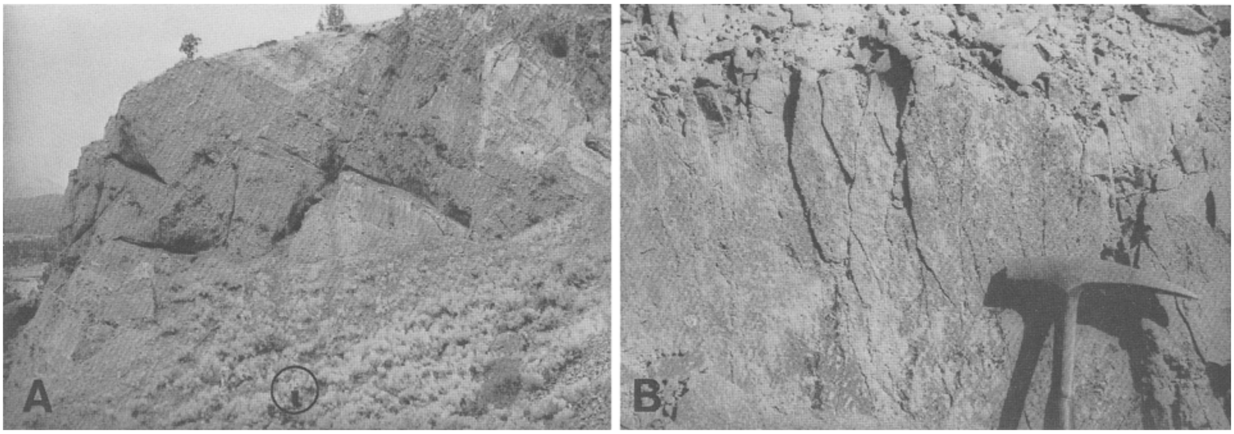

Fig. 2. a A typical section of a hummock, exposing a single faulted block. Note a person (circled) for scale. **b** Conjugate pattern of jigsaw cracks in a block

blocks), (2) layered volcaniclastic material, and (3) accidental material (generally pieces of sedimentary units underlying Shasta Valley). The lava blocks commonly contain many jigsaw cracks (Fig. 2b) (Ui 1983). Blocks of layered volcaniclastic material are commonly faulted (Fig. 2a; Crandell et al. 1984) or deformed in a plastic manner. The few jigsaw cracks found in volcaniclastic blocks are resitricted to individual clasts. Most hummocks contain both lava and volcaniclastic blocks (Crandell et al. 1984). Blocks consisting of fragmented sedimentary rocks occur within the matrix facies beneath flat areas.

The size of individual blocks is difficult to determine. Each lava or volcaniclastic block is a piece of the old mountain, and the pieces may contain more than one type of material. Also, because exposures generally reveal only a small part of a hummock, blocks may be larger than indicated by measurements within a hummock.

The largest block dimension was measured in each exposure. The largest measured block has a maximum exposed dimension of 280 m. This is a minimum for the actual maximum dimension, because it does not include the unexposed part of the block. Measured block size in hummocks decreases with distance from the source (Fig. 3a), as if blocks disaggregated during transport. Measurements of blocks contained within matrix facies in flat areas were not included in Fig. 3a, because these blocks were probably broken off the larger blocks that form the hummocks.

The maximum exposed dimensions of the three largest blocks of layered volcaniclastic material average 220 m. Those of massive andesite average 110 m. This difference may reflect different material behavior: blocks of andesite deformed in a brittle manner, breaking up into small pieces during transport, but blocks of layered volcaniclastic rock deformed in a relatively plastic manner and did not break apart. An alternative explanation is that quarries or roadcuts are easier to construct within poorly-consolidated volcaniclastic materials, increasing the chance of seeing large blocks and hence producing an observational bias.

Most blocks within the matrix facies in flat areas are less than 15 m across (triangle in Fig. 3b). Data are sparse but suggest that block size decreases with increasing distance from source (Fig. 3b). Blocks of accidental sedimentary rock (typically fluvial or lacustrine sandstone and siltstone) are most common in the distal parts of the deposit (X in Fig. 3b).

The percentage of block facies in each exposure was measured. Relatively small fractured blocks as large as a few tens of centimeters across within the matrix facies were counted as block facies. The percentage of the block facies in hummocks is nearly 100% as far as 55 km from the source (Fig. 4). Two hummock exposures between 45 and 50 km from the source are composed of 70% and 30% blocks respectively.

Exposures in the flat areas consist mainly of the matrix facies with less than 20% of the block facies. The percentage of blocks decreases out to a distance of 47 km but increases to 50–60% at 50–53 km, where blocks of accidental fragments are found (X in Fig. 4). This suggests progressive incorporation of the loose surface debris from Shasta Valley into the matrix facies as the avalanche moved.

Jigsaw cracks in blocks

We sampled the number of jigsaw cracks by counting those in a 1 m span of an exposure. For blocks of layered volcaniclastic rock, counts were made selectively for the larger volcanic clasts, and the data were normalized to a 1 m span. Because the number of cracks varies in a single exposure, counts were made at several sites in each exposure. Mean values are plotted in Fig. 5 against distance from source. Blocks from lava flows or domes are much more fractured than other blocks.

The mean number of jigsaw cracks per meter is 14.3 for massive andesite, 7.2 for clasts in layered volcaniclastic

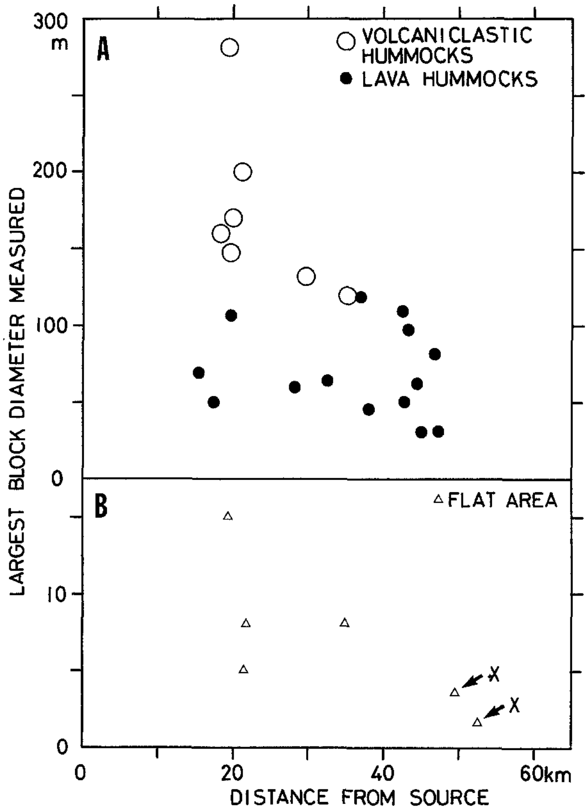

Fig. 3. Largest block diameter measured in each exposure versus distance from source. Data points classified as in Fig. 1; those marked "X" are blocks of accidental materials

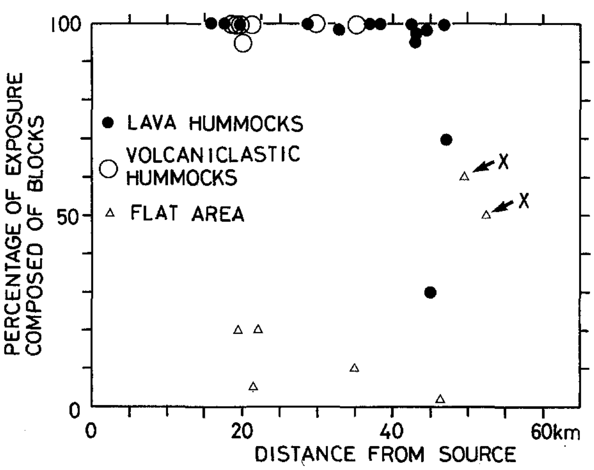

Fig. 4. Estimated percentage of blocks in each exposure versus distance from source. Symbols as in Fig. 3

rock, and 7.6 for small blocks in the matrix facies. A conjugate set of jigsaw cracks (Fig. 2b) commonly occurs in blocks of massive andesite; thus the jigsaw cracks probably formed under a local compressional stress regime (Ui et al. 1986a). Fewer jigsaw cracks occur in clasts of layered volcaniclastic rock; perhaps the compressional stress was attenuated in the relatively fine-grained parts of the rock.

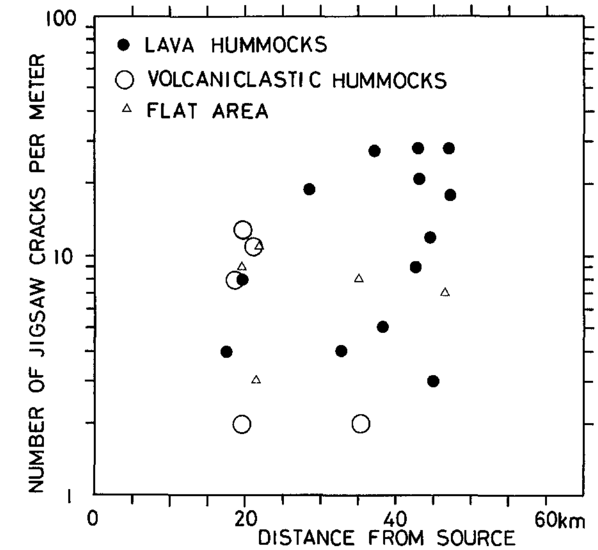

Fig. 5. Number of jigsaw cracks per meter versus distance from the source. Data points as in Fig. 1

The density of jigsaw cracks is not correlated with distance from source (Fig. 5). Therefore most of the cracks probably did not result from transport. Some cracks likely formed at or near the source volcano, possibly from deformation during viscous magma intrusion, stresses set up during initial sliding, or an explosion associated with the initial slide. Similar processes have also been suggested for disaggregation of the Mount St. Helens debris-avalanche deposit (Glicken 1986). A possible slightly positive correlation of cracks with distance from source for massive andesite (Fig. 5) may indicate that additional fracturing occurred during emplacement of the avalanche, as suggested by Crandell et al. (1984).

The width of each jigsaw crack was measured normal to the crack plane. Width of cracks in andesite blocks may increase slightly with increasing distance (Fig. 6). Figures 5 and 6 together suggest that blocks were fractured primarily on or near the old mountain, fractured somewhat more during sliding, and then gradually loosened, deformed, and expanded during transportation. This progression might have enhanced the mobility of the debris-avalanche as it moved downstream.

Rounded clasts in matrix facies

Lithic clasts in the matrix facies are of two origins. Angular and subangular clasts probably came either from blocks in the avalanche or directly from the source volcano. Stream-rounded clasts were picked up from the surface of Shasta Valley during flow of the avalanche. These consist of Tertiary volcanic rocks, granitic rocks, sandstone, and quartzite. This assemblage is similar to those of conglomerate layers in the Hornbrook Formation (Nilsen et al. 1983) and

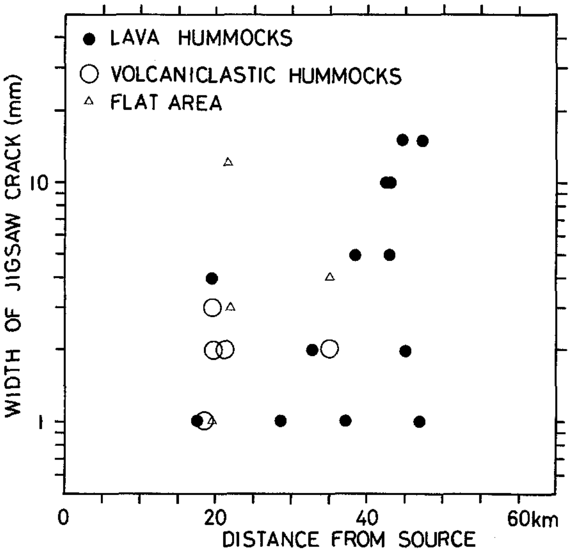

Fig. 6. Width of jigsaw cracks versus distance from source. Data points as in Fig. 1

the Tertiary conglomerate exposed around Shasta Valley (Hotz 1977).

The number of stream-rounded clasts per square meter of matrix exposure increases drastically with distance from source (Fig. 7). Thus, most of the gravel was derived either from alluvial deposits in Shasta Valley, as suggested by Crandell et al. (1984), or directly from the Hornbrook Formation and the Tertiary conglomerate of Hotz (1977).

Comparison to the Pungarehu debris-avalanche deposit of Mt. Egmont

Ui et al. (1986a) applied the same methods of measurement to the Pungarehu debris-avalanche deposit at Mount Egmont, New Zealand. Data for the Egmont deposit differ in some respects from those for the Shasta deposit.

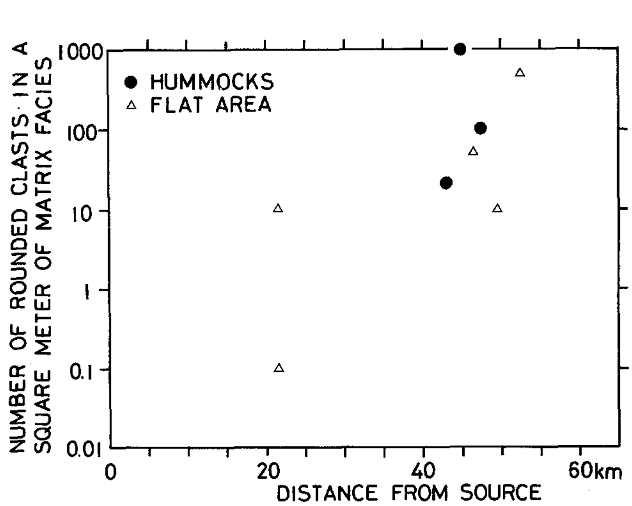

Fig. 7. Number of rounded clasts in matrix facies versus distance from source. Data were obtained from matrix facies in hummocks and from flat areas

In the Egmont deposit, the number of jigsaw cracks increases with the size of the blocks. Ui et al. (1986a) interpreted most of these cracks to have formed before the start of sliding and during acceleration of the slide by collisions against bedrock. A collision mechanism of jigsaw crack formation was judged possible only for blocks larger than 10 m in diameter. All measured blocks in the Shasta deposit are this large, yet no correlation between block size and number of cracks was noted.

A gradual increase in width of jigsaw cracks during movement of the lava blocks is suggested for both deposits. Jigsaw cracks wider than 10 mm are common in the downstream area of the Egmont deposit (fig. 3B of Ui et al. 1986a). Highly deformed small and elongate blocks of massive andesite are common in the distal and marginal parts of the Egmont deposit (Ui et al. 1986a). Such deformation is rare in the Shasta deposit. This difference may reflect lateral spreading of the Pungarehu debris-avalanche onto the coastal plain instead of being confined within a closed basin as for the Shasta debris-avalanche. Thus, hummocks are sparse downstream in the Egmont deposit but relatively closely-packed at Shasta.

The estimated maximum elevation difference from the top of the pre-avalanche volcano to the distal end is 2.5 km for the Egmont deposit and 3.6 km for the Shasta deposit. This suggests that fracturing during sliding should have been much greater in the Shasta deposit, but the actual degree of fracturing of massive andesite is similar in both deposits. The blocks are an order of magnitude larger in the Shasta deposit than in the Egmont deposit, where maximum observed size is 42 m. Perhaps the Shasta source material was less fractured before the slide, or possibly any accompanying explosion was smaller at ancestral Mount Shasta than at Mount Egmont.

Grain-by-grain grinding of polygonal volcanic clasts in the matrix facies, inferred for the Egmont deposits, is also suggested for the Shasta deposit. However, no gradual rounding of polygonal clasts was observed in the Shasta deposit, perhaps because of inadequate exposures.

Conclusion

Internal structural parameters of a debris-avalanche deposit derived from ancestral Mount Shasta were measured in the field. The deposit consists of a block facies and a matrix facies. Three different types of blocks are recognized: (1) blocks derived from lava flows or domes, (2) blocks of layered volcaniclastic rocks, and (3) blocks of accidental sedimentary material. The maximum block dimension exposed is 280 m. The mean maximum dimension for the three largest exposed volcaniclastic blocks is 220 m, and for the lava blocks, 110 m, perhaps reflecting differences in material behavior.

Blocks in the Shasta deposit are an order of magnitude larger, and the height of collapse was 1100 m greater, than for the Egmont deposit, although the degree of fracturing is similar in both deposits (Ui et al. 1986a). This suggests either that the Shasta source material was less broken or that any accompanying explosion at the ancestral Mount Shasta was smaller.

A gradual loosening of broken blocks during transport is inferred for the Shasta deposit but was apparently less than for the Egmont deposit (Ui et al. 1986a), possibly because the Shasta debris avalanche was deposited in a closed basin, whereas the Egmont debris-avalanche spread onto a coastal plain (Ui et al. 1986a). Stream alluvium and bedrock picked up from the underlying material were incorporated within the distal parts of both avalanche deposits.

Acknowledgments. This study was carried out while the senior author was visiting the U.S. Geological Survey on leave from Kobe University. Valuable comments and discussions for this study by D. R. Crandell and R. L. Christiansen are much appreciated. Discussions in the field by A. T. Anderson, Y. Kawachi, and K. Suzuki-Kamata are also appreciated. We thank D. R. Crandell, L. Siebert, R. L. Christiansen, K. M. Scott and two anonymous referees for improvements of the manuscript. Expenses of this study for the senior author were provided by a research grant for scientists in foreign countries by the Ministry of Education, Science and Culture, Japan (Grant No. 58-KO-186).

References

Crandell DR, Miller CD, Glicken HX, Christiansen RL, Newhall CG (1984) Catastrophic debris avalanche from ancestral Mount Shasta volcano, California. Geology 12: 143–146

Glicken H (1986) Rock-slide debris avalanche of May 18, 1980, Mount St Helens Volcano. Ph D Dissertation, University of California, Santa Barbara

Hotz PE (1977) Geology of Yreka Quadrangle, Siskiyou County, California. US Geol Surv Bull 1436: 1–69

Nilsen TH, Barats GM, Eliott MA, Jones DL (1983) Geologic map of the outcrop area of the Hornbrook Formation, Oregon and California. US Geol Surv Open-File Rep 83-373

Ui T (1983) Volcanic dry avalanche deposits. Identification and comparison with nonvolcanic debris stream deposits. J Volcanol Geotherm Res 18: 135–150

Ui T, Kawachi S, Neall VE (1986a) Fragmentation of debris avalanche during flowage. Evidences from the Pungarehu Formation, Mount Egmont, New Zealand. J Volcanol Geotherm Res 27: 255–264

Ui, T, Yamamoto H, Suzuki-Kamata K (1986b) Characterization of debris avalanche deposits in Japan. J Volcanol Geotherm Res (in press)

Received January 13, 1986/Accepted April 4, 1986