OBSERVATIONS ON BURIED SURFACE HOAR IN BRITISH COLOMBIA, CANADA: SECTION ANALYSES OF LAYER EVOLUTION

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ABSTRACT: Observations on sections cut through buried surface hoar layers over time offer the opportunity to measure microstructural changes associated with strengthening. We present preliminary results of new analyses carried out with measurements on sections from snow sampled every week to ten days from mid-winter to late winter over four years, 1995-1998, in British Colombia, Canada. Our measurements focused on changes in basic geometry of buried surface hoar layers, particularly where the buried surface hoar crystals were bonded to the underlying snow. As with previous results, over time the thickness of the layer containing surface hoar crystals decreased as strength increased. In samples from sloping snow, the effect of creep was evident in changing orientation of the cut profiles of buried surface hoar. We attempted to identify bond lines using Kry's criteria to assess bond area density, size and change. Results show that low shear strength of buried surface hoar stems from low area density of bonds at the base of layers of surface hoar crystals. The bond number density increases around the bases of some crystals over the course of several weeks. These measurements seem to support a recent conceptual model involving differential settlement of the buried surface hoar crystals, but evidence was statistically inconclusive pending more measurements.

Keywords: avalanche, snow metamorphism, snow strength, snow crystal, snow cover structure

1. INTRODUCTION

Buried surface hoar represents a serious problem to avalanche forecasting because critical weakness that can cause avalanche release persists long after other types of instabilities in snow cover have disappeared (Jamieson and Johnston, 1995). Recent research has focused on improving our understanding about factors that control the strengthening of buried surface hoar layers. Jamieson (1995) tracked surface hoar layers soon after burial using measurements of shear strength, rutschblock (Föhn, 1987) and conventional snow pit observations (CAA, 1995). Decreases of avalanche releases were associated strengthening of the buried surface hoar, which in turn was related to several other factors. Davis et al. (1997) made measurements on sections cut through undisturbed samples of snow containing buried surface hoar. Samples were collected from the same layers over weeks to track changes. Thinning of the surface hoar layer and densification of the overlying and underlying strata were associated with strengthening. Little change was observed of the surface hoar crystals, as exposed on sections cuts. More recently, Jamieson and Schweizer (submitted) have developed new techniques for observing these layers *in situ*. They have formulated a conceptual model of strengthening that involves preferential settlement, on a microscopic scale, of the wedge-shaped crystals into the substratum. This would promote bonding along the sides of the hoar crystals, which are resistant to metamorphic changes due to their relatively large size. This paper presents a preliminary study that focuses on the buried surface hoar crystals as exposed on section cuts. This was essentially a reanalysis of samples described by Davis et al. (1997), along with new samples collected over time from other test areas. Rather than repeat the previous work we developed some new image processing methods to examine the early and late stages of the evolution of buried surface hoar layers. Specifically, we explored the feasibility of the conceptual model of Jamieson and Schweizer (submitted).

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2. METHODS

Test sites were visited every 9-14 days, to make measurements of surface hoar layers starting soon after they were buried. Specimens representing time series were collected every one and a half to two weeks during the winters 1994-1998. Samples from two sites were used in this study: 1) The Mt. St. Anne Research Plot is a large level bench at 1900m on the east slope of Mt. St. Anne in the Cariboo Range (part of Columbia Mountains in western Canada). During the last two winters the snow pack ranged from 175 to 375 cm during the field season; 2) The North Moose Study Slope is a 20-34 degree cut-forest block at 1900 m on a NW slope in Vowell Valley of the Purcell Range (part of Columbia Mountains in western Canada). During the last two winters the snow pack depth ranged from 111-217 cm during the field season.

On each test day, we located the buried layer of surface hoar on the side wall of a snow pit and sampled the snow for section plane analysis,. One can measure some snow properties on section cuts at scales and in ways not currently possible with simple tools in a snow pit (Good and Krüsi, 1993). An undisturbed specimen consisting of the surface hoar layer and the layers above and below was collected from the side wall of the pit (Figure 1). The specimen was isolated from the pit wall and gently placed in a 15 cm long by 10 cm wide by 5 cm deep box. The snow was mechanically stabilized and sealed using dimethyl phthalate as a pore filler (Perla, 1982), which was subsequently frozen.

Figure 1. Coauthor sampling snow with buried surface hoar layer for section analysis.

In the cold laboratory, we mounted and planed specimens on a sledge microtome to produce a smooth surface, which was subsequently polished. Left in the cold room for some hours, the exposed ice preferentially sublimated. The resulting etch pits were filled with photocopy toner to create high contrast between the ice grain profiles and the pore filler. A video camera and frame grabber acquired digital images of the section cuts and grid scales. Image processing included threshold enhancement, edge detection and manual image editing to produce new images on which the profiles of buried surface hoar cut by the plane could easily be observed and measured.

We examined changes in the proximity of the upper and lower boundaries of the buried surface hoar, the relative positions of hoar crystal profiles and the number and location of bonds around the bases of the hoar crystals using the earliest and latest samples from each test series. A combination of image mosaics, images at high and low magnification, visual inspection under magnification and Kry's (1975) criteria provided guidance to the somewhat subjective task of identifying bonds. A bond was noted if contact was visible at the base of the buried surface hoar layer, if there was spatial continuity with a sizeable profile and if it appeared as either a thin parallel-sided connection, or consisted of facing constrictions with at least 15 percent narrowing (Kry, 1975). The number of bonds was counted along an arbitrary line. Each sample count used 5 cm of section. Our test line consisted of a subjectively drawn mark that delineated the surface of the substrate on which the surface hoar crystals grew.

We also recorded a snow profile (CAA, 1995). As part of the snow profile, we disaggregated and observed surface hoar crystals on a dark-colored metal plate with a 3 mm grid. The shape and size of the crystals was recorded (Colbeck and others, 1990). We also photographed the disaggregated crystals on the metal plate for most of the tests. We removed the overlying snow to within 45 mm of the surface hoar layer and made 7-12 shear frame tests each day (e.g. Sommerfeld, 1984; Jamieson and Johnston, 1995). Thorough analyses of the field data can be found in Jamieson and Johnston (1998).

3. RESULTS

Four pairs of samples were processed. The first three were from the Mt. St. Anne study plot: 1) 07 January and 08 March 1995; 2) 05 January and 02 March 1996; 3) 20 February 1997and 20 March 1997. The forth set were from the dates 18 February and 18 March 1998, from North Moose Study Slope. Different types of crystal profiles were observed.

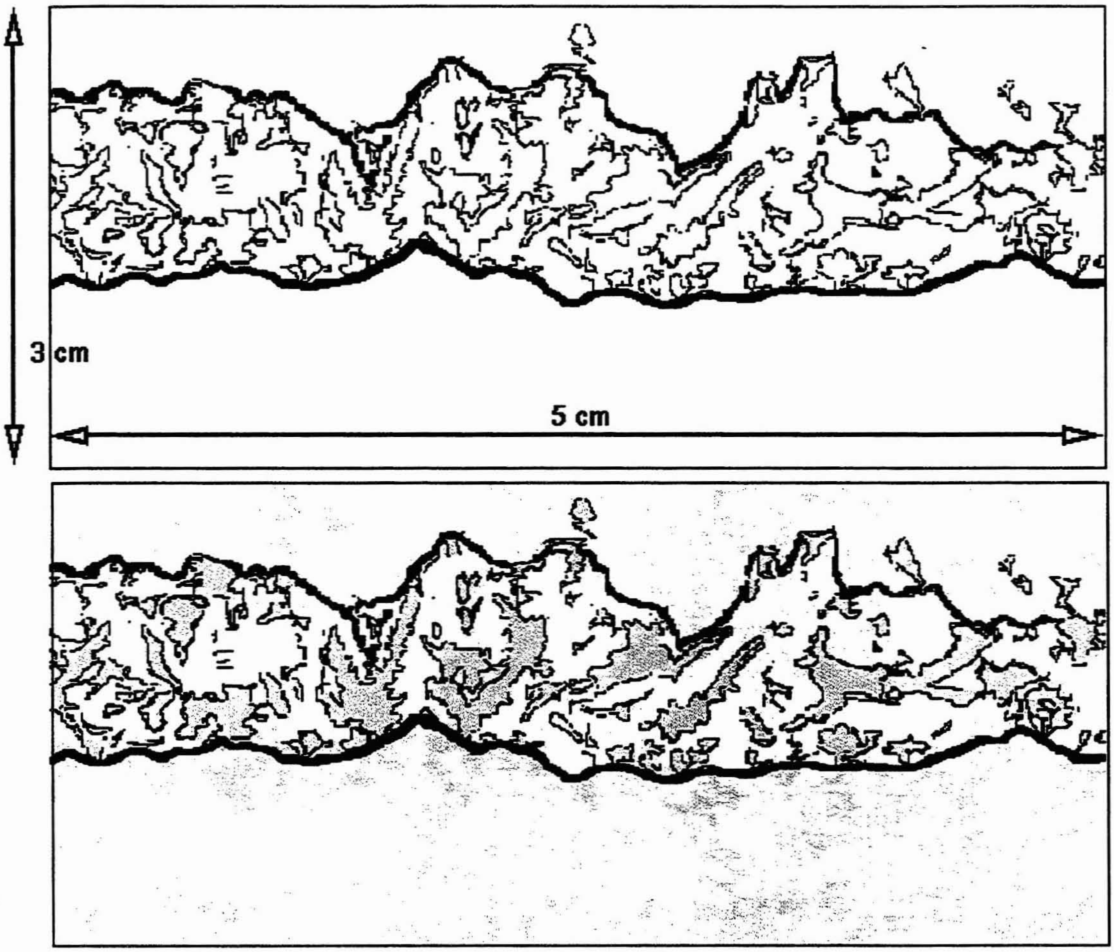

Figure 2. Processed image (2a – top) showing buried surface hoar layer sampled from Mt. St. Anne 07 January 1995. Profiles of hoar crystals exposed by the cut are outlined with thin black lines. Inferred substratum and superstratum surfaces shown by bold black lines. Superposition of processed and raw digital section images (2b – bottom) qualitatively shows relative texture of layers.

Broad forms of surface hoar showed the most pronounced umbrella effect, resulting in large cavities relatively devoid of grains or particles related to the superstratum. Thin plates, which manifested on section cuts as thin lines, showed less of this effect.

Two sets of samples showed the broad type of surface hoar crystals. Figure 2a shows a fully processed image in which the profiles of cut hoar crystals have thin outlines, and the approximate boundaries of the superstratum and substratum have thick lines. Figure 2b shows the fully processed image superposed over a mosaic of two raw section images to illustrate the relative texture of the layers. Figure 3a shows a processed image of the same layer about seven weeks later, and Figure 3b shows a similar superposition as Figure 2b. These images showed clear evidence of the penetration of a buried surface hoar crystal into the substratum. The wavy character of the substratum surface on other cuts also showed some partial profiles of surface hoar crystals that penetrated into depressions, but were not as clear examples.

Other sets of samples showed evidence of creep, due to a sloping surface on which the surface hoar grew. Figure 4a shows a fully processed image of the start of the test period and Figure 4b shows the superposition of the processed and raw images. The surface hoar crystals were of a thinner-walled type, leaving thin traces on the section cut. Figures

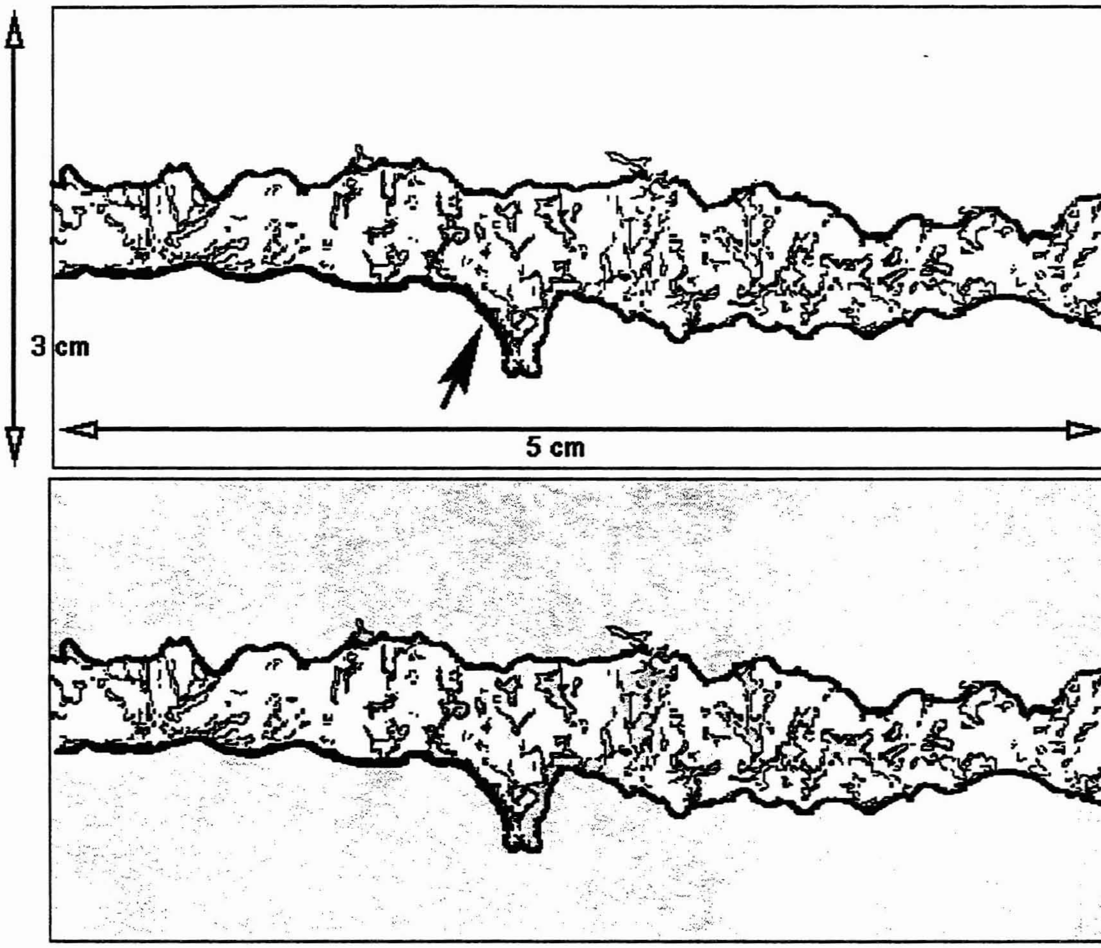

Figure 3. Processed image (3a – top) showing buried surface hoar layer sampled from Mt. St. Anne 08 March 1995. Profiles of hoar crystals exposed by the cut are outlined with thin black. Inferred substraum and superstratum surfaces shown by bold black line. Arrow shows profile of surface hoar crystal penetrating substratum. Superposition of processed and raw digital section images (3b – bottom) qualitatively shows relative texture of layers.

5a and 5b show the same layer eight weeks later. There were two locations on this section that showed evidence of penetration of the surface hoar crystals into the substratum (center and left – Fig. 5b), but the predominant effect of aging of this layer was the inclining of the hoar crystals. In many cases the outlines of the inclined surface hoar crystals could be seen in contact with each other and between their sides and the adjacent strata.

As with other results in the laboratory and field (Davis et al., 1997; Jamieson and Johnston, 1998), the thickness of the buried depth hoar layer decreased during the test period. In the four pairs of sections, the variance in layer thickness decreased over time, proportional to the average thickness. Figures 2-5 show examples, and the results were comparable to Davis et al. (1997). Outlyers in the statistics were predominantly associated with crystal penetration.

Bonds were extremely tedious to identify from the various processing steps. The counts were not statistically reasonable in number despite several section cuts per specimen, which basically showed that obvious bond profiles were relatively rare. Table 1 summarizes the number of bonds identified along the base of the buried surface hoar for each date. Values represent averages of at least two test lines on different cuts per specimen.

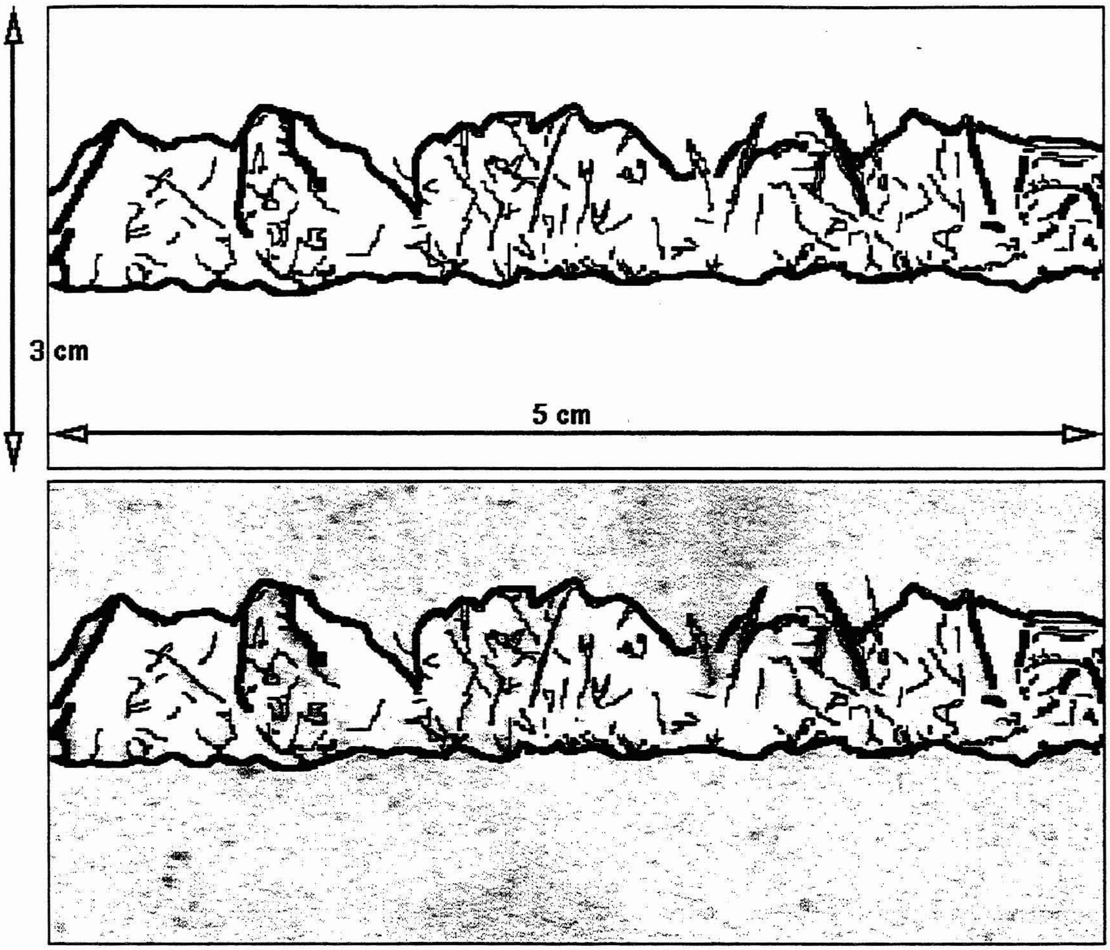

Figure 4. Processed image (4a – top) showing buried surface hoar layer sampled from Mt. St. Anne 05 January 1996. Inferred substratum and superstratum surfaces shown by bold black line. Superposition of processed and raw digital section images (4b – bottom) qualitatively shows relative texture of layers.

The two section series that showed the greatest increase in bond count had evidence of penetration of the surface hoar crystals into the substratum. However, counting bonds, or simply contacts of ice profiles in this case, was more subjective. The number per cm^2 of the apparent bonds can be estimated by squaring the values in Table 1 and dividing by 25. The area bond density in the superstratum and substratum exceed these values by factors of 5 and more.

Table 1. Numbers of bonds at base of surface hoar crystals along a 5 cm test line.

Mt. St. Anne		
date	950107	950308
bond count	25	>50
date	960105	960302
bond count	22	41
date	970220	970320
bond count	27	>50
North Moose		
date	980218	980318
bond count	33	49

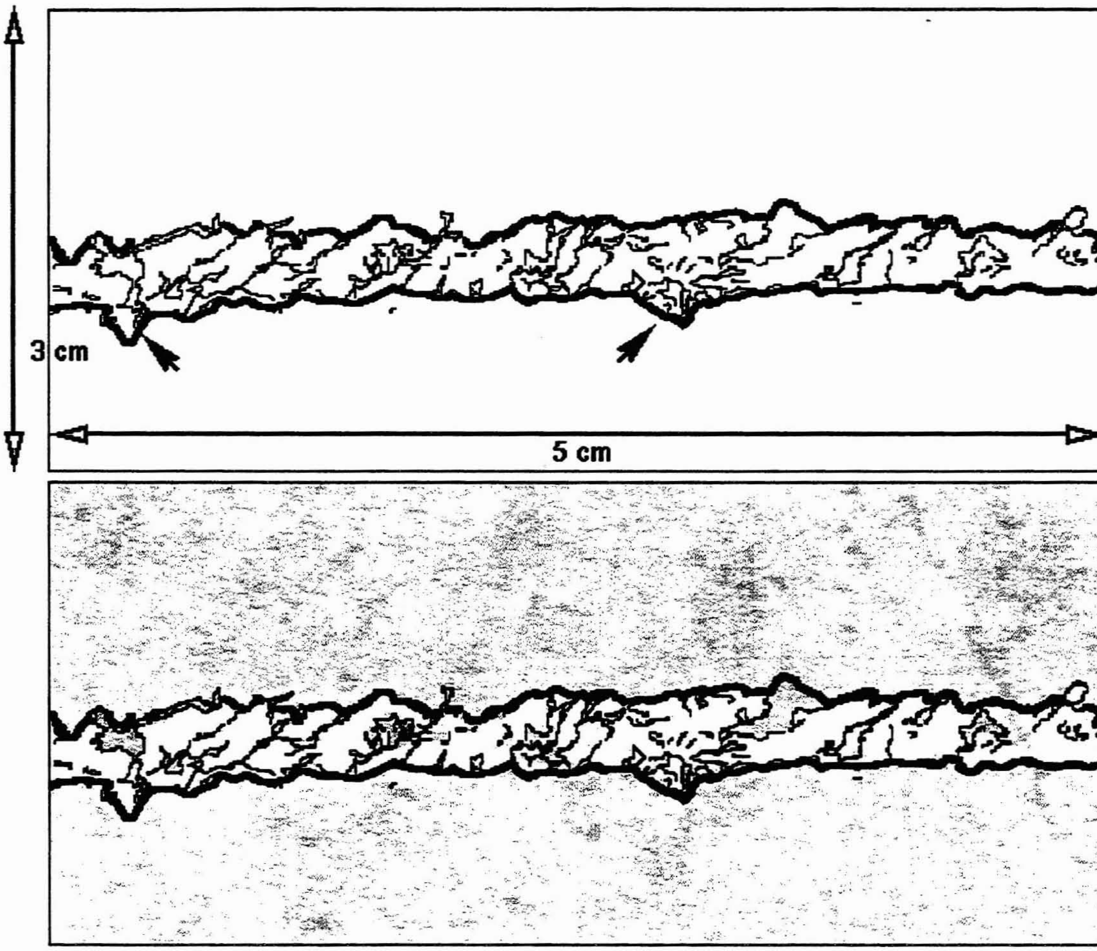

Figure 5. Processed image (5a – top) showing buried surface hoar layer sampled from Mt. St. Anne 02 March 1996. Profiles of surface hoar crystals strongly inclined to right. Arrows show hoar crystal penetrating substratum. Superposition of processed and raw digital section images (5b – bottom) qualitatively shows relative texture of layers.

4. DISCUSSION

This feasibility study showed evidence that the processes of differential settlement and creep can cause the increase in the number of subjectively identified bonds at the base of buried surface hoar layers. We found several instances where penetration of hoar crystals into the substratum was obvious, and the Figures presented above show the best examples. This follows the idea that the differential settlement of the surface hoar crystals brings them into contact with many grains from the underlying layer, which then form bonds. Creep inclines buried surface hoar crystals over time, which also appears to result in a greater number of contacts and thus to offer good reasons for strengthening. However, as discussed by Dozier et al. (1987) we feel that we cannot objectively identify all bonds exposed by a section cut. Arons and Davis (1995) found this was the case for serial cuts as well. The occurrence of bond-like contacts between a buried surface hoar layer and the substratum were rare in these sections, which were large cuts, about 10 cm across. Thus it seems that the less ambiguous identification of bond lines via the use of thin sections would represent a significant undertaking, since several sections per sample would have to be prepared to obtain reasonable statistics.

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