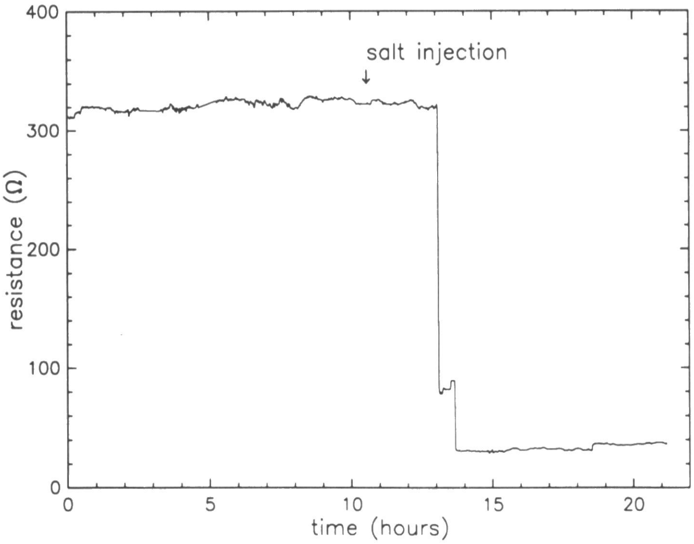

Figure 3. Results of salt injection experiment is used to monitor the basal hydraulic transport velocity. Two hours are needed for salty water to travel from the injection borehole to a pair of boreholes 60 meters downstream where the arrival is sensed by a drop in resistance between the boreholes.

way, Scot Duncan, Tomas Svitek, and Judith Zachariasen. This work was supported by National Science Foundation grant DPP 85-19083. Contribution No. 4896, Division of Geological and Planetary Science, California Institute of Technology.

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Studies of internal layering and bedrock topography on ice stream C, West Antarctica

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During the 1987–1988 and 1988–1989 antarctic field seasons, surface-based ice-radar profiling studies were done on ice streams B and C by a collaboration between the U.S. Geological Survey and St. Olaf College. The system used has been discussed by Wright, Hodge, and Bradley (1989) and Wright et al. (in press) and the field program and preliminary results are described by Hodge, Jacobel, and Wright (1989). In this article, we summarize progress to date on the analysis of a portion of these data acquired near the Upstream C camp (136°33′W 82°24′S) in 1988–1989.

Data were acquired along two transverse profiles 95 kilometers in length and 1 kilometer apart which extended across the entire ice stream and into both marginal shear zones. Three longitudinal lines 28 kilometers long and 1 kilometer apart were profiled along the Ohio State strain grid, and a 5-by-12-kilometer subsection of the strain grid was studied in detail with profiles spaced approximately 1 kilometer apart. All data on ice stream C were acquired at a 4-megahertz center frequency of the short-pulse radar. Data densities were either 2 or 4 meters per recorded waveform with each record resulting from stacking (adding) 8,192 individually digitized returns acquired in the 2- or 4-meter interval. Figures in this report use further data compression to fit profiles on a single page and so do not depict the full resolution and details actually present in the data.

Figure 1 shows a contour map and mesh diagram of ice thickness beneath the center portion of the strain grid. Because the surface elevations change by only a few meters in this area, it is also a good approximation of the bedrock topography. Overall relief is about 170 meters beneath ice which averages about 1,000 meters in thickness. The transverse profiles which intersect this grid show that it contains the highest bedrock topography (shallowest ice) in this entire survey where thickness ranges from 938 to 1,340 meters. Thus, the strain grid is coincidentally located nearly in the center of a local bedrock high which slopes upward in the direction of flow.

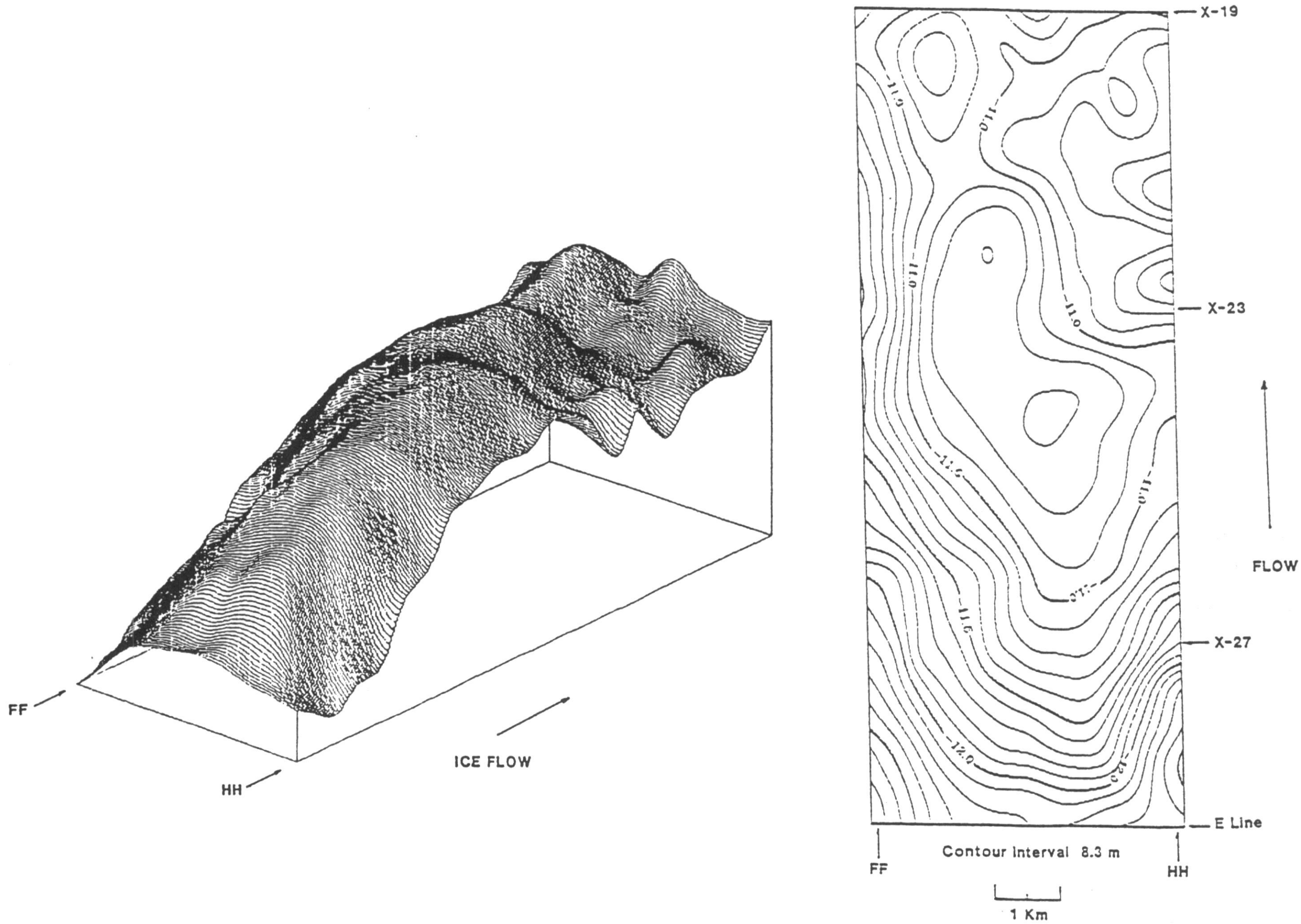

Figure 1. Ice thickness contour map and mesh diagram (essentially equivalent to bedrock topography) for a 5-by-12 kilometer region of the strain grid near the Upstream C camp. (km denotes kilometer. m denotes meter.)

There appears to be a strong correlation between the bedrock topography, and surface features and velocities in the area, even though ice stream C is nearly stagnant (Whillans, Bolzan, and Shabtaie 1987). The Landsat thematic mapper image of this portion of the ice stream taken at low angle Sun illumination shows patterns of streamlines diverging around the area of the strain grid which appears to have a more undulating surface and lower velocity. This suggests that local topography is exerting a strong control on ice velocities in this area. In addition to determining bedrock topography, the radar data also give estimates of bed roughness. Together these results will be compared with force balance model calculations of bed stresses now being carried out by Ohio State from their strain rate measurements.

A second focus of our investigation concerns the internal layering, which is perhaps the most remarkable feature of these radar data. Figure 2 shows a section of one of the longitudinal profiles (line HH) along the right-hand margin of the map in figure 1. This figure is a gray-scale reproduction of a color original where color (hue) has been scaled to radar echo amplitude. The product has less contrast than the original color image but adequately illustrates the points of this discussion. Figure 2 is typical of most of the data and shows deformation of the internal layers which bears no simple relation to the bed or surface topography. The amplitude of the deformation is larger than the local bed relief and decreases upward throughout the section. A smooth shift in phase also occurs in the vertical direction, with the phase shift increasing in the flow direction. The magnitude of this phase shift allows a calculation of the accumulated vertical shear strain of the ice as it has moved from the region where folding is produced, and this shear strain can be used to infer the time since folding occurred.

Folding in the internal layers can be easily matched between adjacent parallel profiles, and also between longitudinal and transverse lines. We are currently constructing a contour map of the deepest of these surfaces, similar to the bed map in figure 1, to further understand the dynamics of ice-stream flow. Interpretation of this pattern of folding is not straightforward since it does not appear to correspond to anything studied or seen before. Folding of internal layers in the ice sheet near Byrd Station above the ice streams has been modelled by Whillans and Johnsen (1983) and bed topography together with variable drag at the bed produces variations in surface topography, strain rates, and deformation of internal layers which correlate well with the data. In the present case, however, there appears to be no simple correspondence between measured strain rate variations on the surface and the pattern of internal layer deformation, or even with the bedrock topography. The process producing these folds must, there-

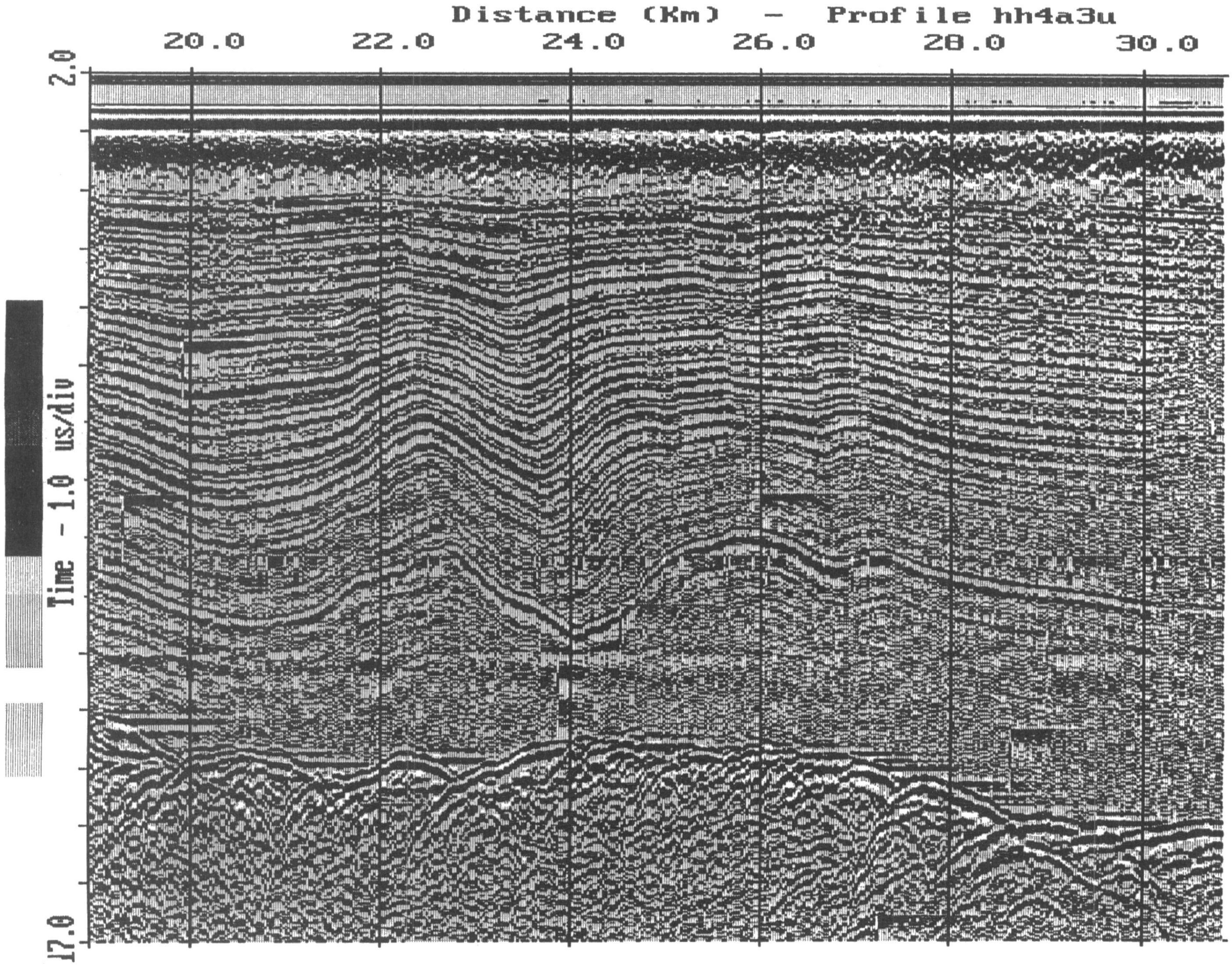

Figure 2. Longitudinal profile along the HH margin of figure 1. Flow is to the left. Ice surface is at 2.6 microseconds. Bed and associated roughness features are seen at 13 to 15 microseconds (approximately 850 to 1,030 meters). Vertical exaggeration is approximately 5.6 to 1. Folded internal layering is evident throughout the section with a vertical phase shift increasing in the flow direction. This shift provides a measure of the accumulated vertical shear strain and allows an estimate to be made of the time since the folding occurred. (km denotes kilometers.)

fore, occur somewhere upstream, perhaps in a transition region where the onset of ice streaming occurs. Support for this idea comes from the large accumulated vertical shear strains which indicate a considerable length of time since the folds were produced, and thus a location well upstream.

The 95-kilometer long transverse profiles also show folding of the internal layers (figure 3). In this case, the profiles show a variation in the wavelength of the folds which appears to correspond to the features seen in the thematic mapper image discussed above. In the "streaming" areas on either side of the topographic high, wavelengths are about 1 to 2 kilometers (sides of figure, +20 kilometers to +5 kilometers and −10 kilometers to −30 kilometers), whereas in the region of the central topographic high (center of figure, +2 kilometers to −8 kilometers), the wavelengths are about 4 kilometers, in both longitudinal and transverse profiles. Transverse folding presumably results from compression and may also be initiated at the onset of streaming where fast flow begins, although the reason for the variations in length scale is not yet clear.

Work on this data analysis has been supported by National Science Foundation grants DPP 85-17225 and DPP 89-15850 to St. Olaf College. Development of the system was done by the U.S. Geological Survey and field work by the U.S. Geological Survey and St. Olaf College. Undergraduates Dave Gottschling and Stefan Anderson have assisted in the data processing and reduction which has been carried out primarily at St. Olaf College and INSTAAR, University of Colorado, Boulder where Jacobel has been on sabbatical leave.

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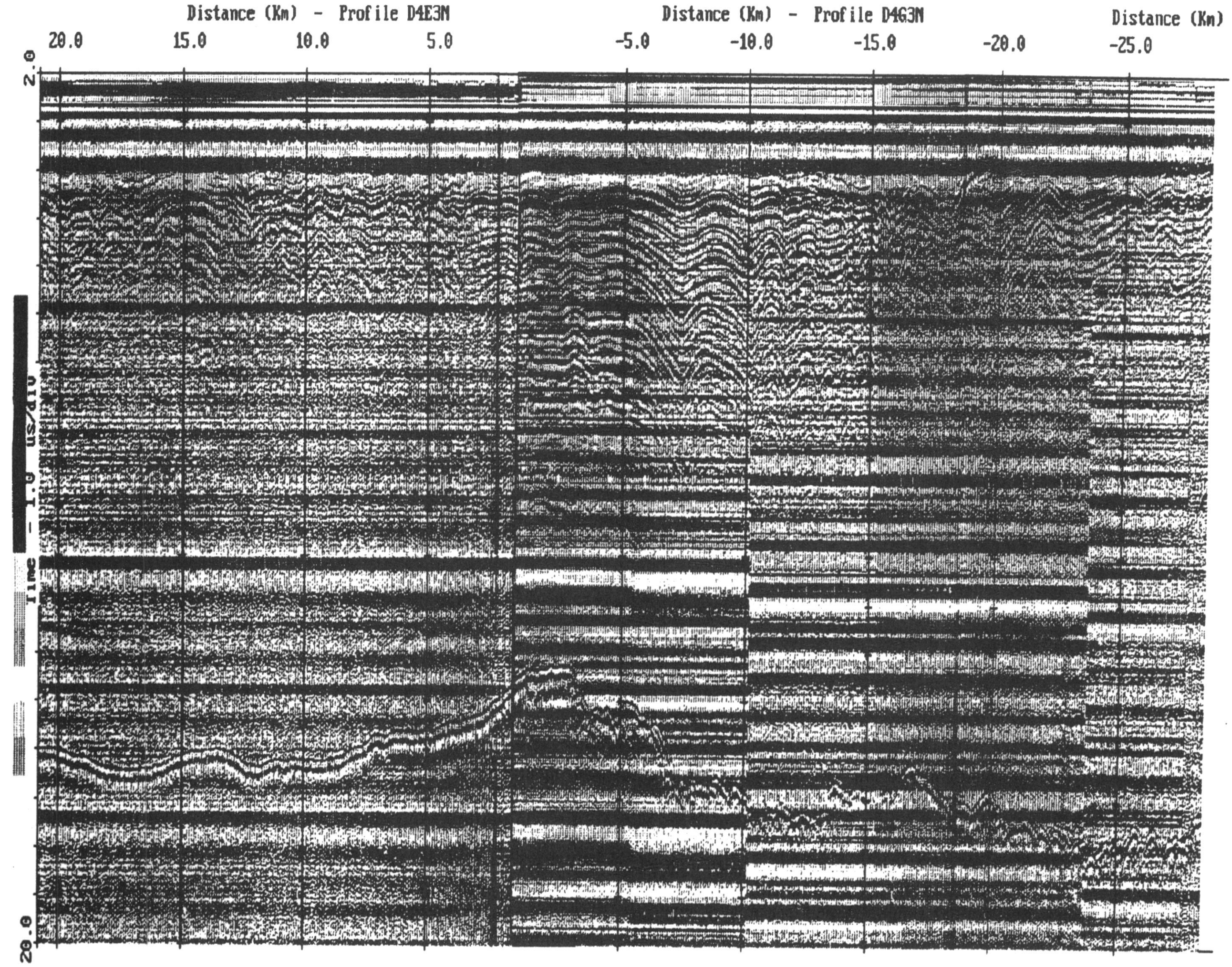

Figure 3. Portion of the 95-kilometer transverse profile which crosses the upstream end of the grid in figure 1. Orientation is looking downglacier; vertical exaggeration is approximately 26:1. Bed and associated roughness features are seen at 14 to 18 microseconds (approximately 950 to 1,340 meters). Horizontal lines, and abrupt discontinuities in them, are system artifacts as described in the text. Note the change of scale from that used in figure 2. (km denotes kilometer.)