RESULTS OF GROUND-PENETRATING RADAR SURVEYS:

THE FARM OF VATNSFJÖRÐUR, NORTHWEST ICELAND

May 2008

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1.0 INTRODUCTION

Reconnaissance ground-penetrating radar (GPR) surveys were conducted between July 2nd and 3rd, 2007, at the farm of Vatnsfjörður, northwest Iceland (Figure 1). The site is the location for an international field school in North Atlantic archaeology, which is operated under the auspices of Institute of Archaeology, Iceland, and is directed by Dr. Karen Malik with the Department of Archaeology, University of Aberdeen. The purpose of the GPR surveys was to assess the usefulness of the method to delineate buried archaeological features of interest. In particular, the electrical contrasts between soil and rocks are expected to produce good GPR signatures (i.e., reflections) under ideal conditions, which may indicate the presence of buried walls or foundations. Limited excavation conducted by the field school helped to "ground truth" the geophysical interpretations.

Summarized below are the results of the GPR surveys. Relevant information and processing results are provided in the appendices: Appendix A gives a brief overview of the GPR method, Appendix B contains the 2-D radargrams; and Appendix C presents the horizontal time-slice images that were produced by combining the radargrams.

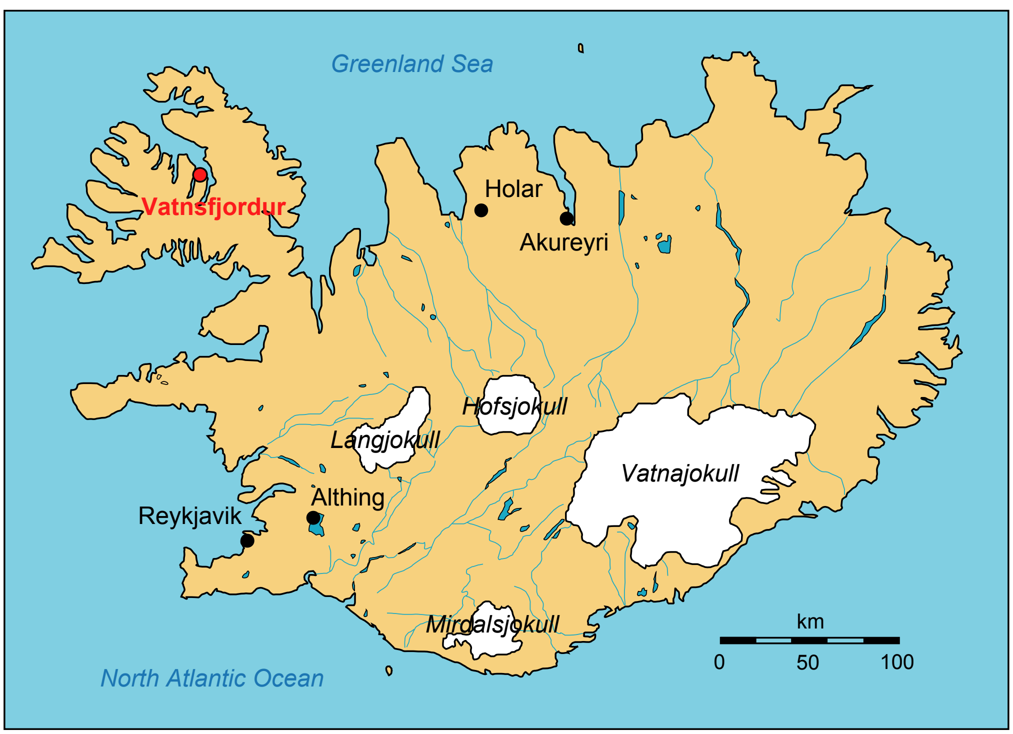

Figure 1: Index Map.

2.0 GROUND PENETRATING RADAR SURVEYS

2.1 Site Conditions

A flat-lying rectangular area covering 5 by 18 m was initially selected for survey by Dr. Milek. This area was subsequently expanded by the addition of a second rectangular area covering 4 by 11 m. Both areas were deturfed in order to expose the underlying soil. Previous GPR studies in other parts of Iceland have indicated that the highest quality data are obtained when the transmitting/receiving antenna lies directly on soil, as opposed to the natural condition which typically is tall damp grass. Surveying on tall grass results in the poor coupling of the antenna with the ground surface, thus limiting the amount of electromagnetic (EM) energy that is pulsed into the subsurface.

A potential site condition that may affect data quality is the presence of groundwater or soil moisture. In general, the presence of water tends to attenuate the EM energy which limits the depth of penetration (see Appendix A). The soil within the survey area is an andosol, which has the capacity to absorb large quantities of water (>100% dry weight basis). The soil did not appear overly moist upon deturfing and there was no rainfall immediately prior to or during the two days of data collection. During surveying, the weather was mild with temperatures between 15 and 20 C.

2.2 Equipment and Field Procedures

All data were collected using a hand-towed Mala Geoscience RAMAC system equipped with an X3M control unit (Figure 2). Two shielded antennas—800 and 500 megaHertz (MHz)—were utilized in separate surveys. In general, the 800 MHz antenna provides higher resolution but lower penetrating power as compared to the latter. As an example, at a depth of 1 m below ground surface (bgs) and assuming an "average" soil with microwave velocity of 0.07 meters per nanosecond [m/ns]), the two antennas provide vertical and horizontal resolutions of approximately 0.02/0.21 m and 0.04/0.27 m, respectively. For both surveys, the pulse rate was set to 0.02 seconds, which yielded a vertical scan at approximately every 0.02 m along the horizontal direction. The recording time window was set to 30 nanoseconds (ns) for the 800 MHz survey and to 63 ns for the 500 MHz survey.

An orthogonal grid was established based on a relative X and Y coordinate system and adopting a transect spacing of 0.25 m (Figure 3). Transects were oriented approximately southwest to northeast, parallel to the long dimension of the grid (i.e., a transect/profile is identified by its Y coordinate). Data collection along a given transect was guided by stretching a fiberglass measuring tape between the endpoints. The

Figure 2: Photo of GPR equipment being used to survey a farm mound at Meðalheimur, Skagafjöður. The survey was conducted using a 500 MHz antenna. The 800 MHz antenna (not shown) is approximately one-half the size of the one pictured here.

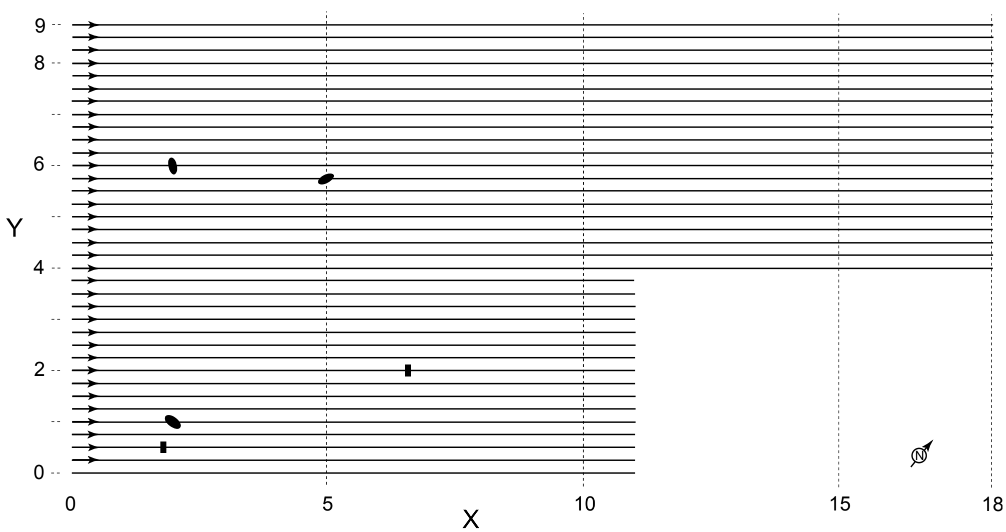

Figure 3: Schematic diagram of grid showing the location and orientation of transects (solid lines with arrows). Solid rectangles denote locations of wooden stakes. Solid ellipses denote rocks on the ground surface. The transect Y = 9 m was traversed only for the 800 MHz survey.

actual location, however, was determined by fiducial markers that were placed into the data stream by the operator at 1-m intervals, and assuming linear interpolation between markers. All transects were traversed in the same direction. In total, approximately 525 linear meters were covered for the 800 MHz survey, and 507 linear meters for the 500 MHz survey (note that transect Y = 9 m was traversed only in the former survey).

2.3 Data Processing

For each transect, three files were recorded: a header file (*.rad), a scan data file (*.rd3), and a marker file (*.mrk). Upon completion of the survey, the raw data were uploaded from the GPR console to a laptop computer. The data were then processed using GPR Slice software (see www.gpr-survey.com; Goodman et al., 1995; Goodman et al., 2006; and Goodman et al., in press).

The scan data were initially corrected for location using the marker file and then resampled to produce 2-D radargrams (vertical profile) of recorded amplitude (i.e., two-way travel time of reflected EM energy). The depth scale was estimated (±25 %) by assuming a velocity of 0.07 m/ns, as determined through analysis of hyperbolic reflections on various profiles. Next, the radargrams were combined to produce a pseudo 3-D data set. Horizontal time-slice images were then generated for various time (depth) windows to provide detailed spatial information on the location and estimated depth of reflectors. Although these images are presented with respect to depth bgs, the term time slice is retained throughout the report. Appendix B contains the processed radargrams for both surveys and Appendix C the processed time-slice images.

3.0 RESULTS AND INTERPRETATIONS

3.1 800 MHz Survey

Inspection of the processed radargrams (Figures B1 through B3, Appendix B) indicates the presence of various strong reflectors, as denoted by the light blue-red bandings that are superimposed over a darker blue background. These reflectors are discontinuous and the majority occurs within the upper 50 to 60 cm bgs, which infers an approximate maximum depth of penetration that can be achieved with this antenna subject to site-specific conditions. Alternatively, there may be a lack or reflectors below this depth or a particularly strong reflector, such as the bedrock surface, which prevents the transmission of EM energy although the discontinuous nature of the banding does not support this contention.

Figure 4 presents several processed radargrams for both the 800 and 500 MHz surveys (lower left and right, respectively), displayed in relation to the results of shallow excavation. The excavation revealed the

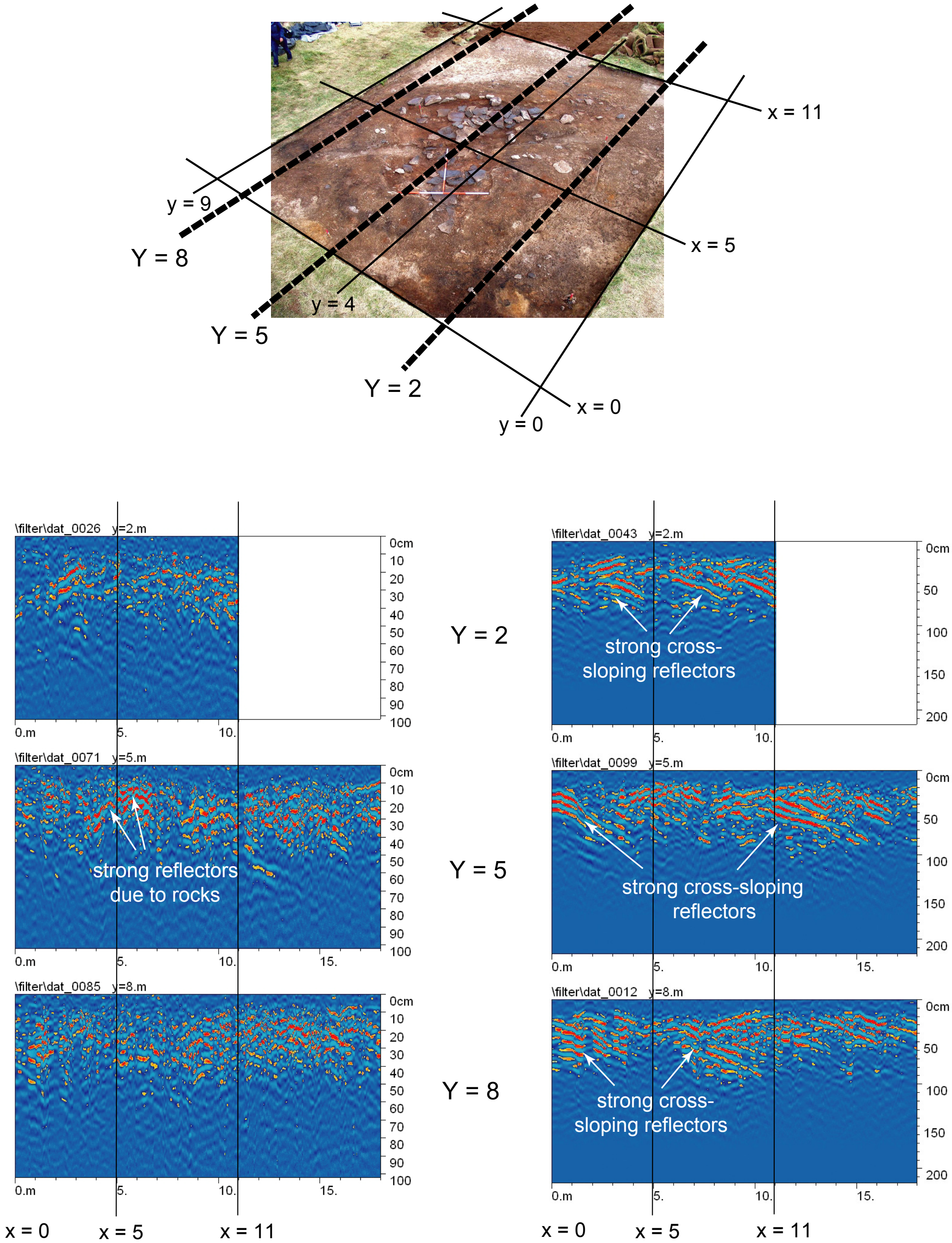

Figure 4: Processed radargrams displayed in relation to shallow excavation. Upper: Photo of shallow excavation with relative grid system superimposed (thin black lines) with coordinates given in meters. Bold dashed lines indicate the location of corresponding radargrams. Left: Processed radargrams for 800 MHz survey. The light blue-red banding indicates a strong reflector. Right: Processed radargrams for 500 MHz survey.

presence of a stone pavement surrounded by turf walls (Karen Milek, personal communication). The wall on the southeastern side of the structure, however, is nearly completely gone. In addition, a narrow trench, probably of recent time, cuts through the walls and central floor deposits. The presence of the pavement stones is clearly evident on the 800 MHz radargram at Y = 5 m, which crossed directly over them. Rocks within soil are expected to produce strong reflections.

The pavement stones are more visually apparent in Figure 5 which depicts two time-slice images. The upper image overlays reflected energy between 12 to 18 cm bgs (i.e., combines the reflected energy from two individual time slices that were processed, b7 and b8, Figure C1), while the lower one overlays 57 to 63 cm bgs (b29 and b30, Figure C1). In these images, red denotes relatively strong reflected energy whereas light greenish and whitish areas indicate weak or absent energy. For the shallower time-slice image (Figure 5, Upper), there is a clear correspondence between two areas with strong reflections and the location of the rocks. The general triangular outline of the pavement stones lying to the north of the narrow trench is accurately delineated. In addition to the strong reflections noted above, there is another area—lying between Y: 8 to 9 m and X: 11 to 14 m—that is interpreted to contain a shallowly buried patch of rocks.

For the deeper time-slice image (Figure 5, Lower), there are several areas with strong reflections, including two pronounced lineations. One of these corresponds to the narrow trench identified by excavation. This feature most likely is either a plough scar or a pipe buried in recent times. Inspection of the radargrams in Appendix B, however, does not indicate the presence of the latter given the lack of pronounced hyperbolic point reflections that would be expected with such a feature. The second lineation, which lies further to the north, is slightly north of the turf wall. It is not clear as to whether this lineation is anthropogenic (e.g., foundation stones) or geologic (e.g., gravel lens) in nature and is tentatively interpreted as the former based on interpretation of the 500 MHz data discussed below. Finally, the strong reflections occurring in the southern portion of the image (i.e., lower left-hand corner) is in the vicinity of the turf wall and is tentatively interpreted as foundation stones.

A general observation of all time-slice images indicates the presence of east-west trending lineations (see Figure C1, Appendix C). These lineations are more apparent below a depth of 40 cm bgs. At this stage, definitive interpretation as to whether all of these are anthropogenic (e.g., plough scars, foundation stones, etc.) or geologic (e.g., gravel lenses) cannot be made.

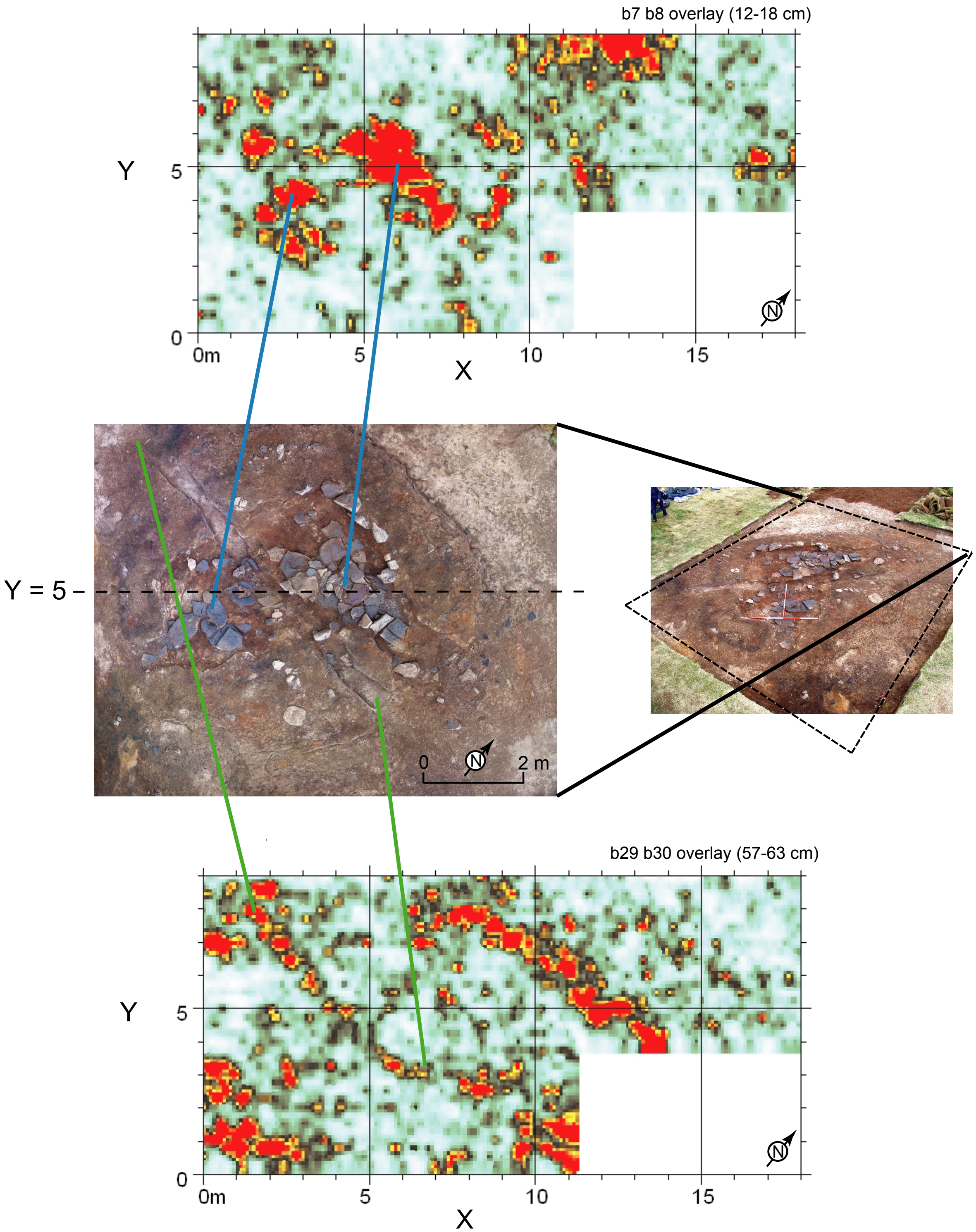

Figure 5: Time-slice images generated from 800 MHz survey displayed in relation to shallow excavation. Upper: Overlay image for 12 to 18 cm bgs. Middle: Photos of shallow excavation. Lower: Overlay image for 57 to 63 cm bgs.

3.2 500 MHz Survey

Inspection of the processed radargrams (Figures B4 through B6, Appendix B) indicates the presence of numerous strong reflectors. The types of reflectors include short discontinuous, long continuous and cross-sloping (-cutting). The majority occurs within the upper 1 to 1.5 m bgs, which infers an approximate maximum depth of penetration that that can be achieved with this antenna subject to site-specific conditions.

Several processed radargrams, displayed in relation to the results of excavation, are depicted in Figure 4 (lower right). Distinct cross-sloping reflectors are noted that correspond to the location of turf walls which is interesting given that in surveys conducted elsewhere in Iceland, turf walls generally produce weak reflections. The orientation of profiles cross the turf walls at an oblique angle, as is noted by the greater separation distance between opposing reflectors for the radargram at Y=5 m—which crosses through the center—versus the radargrams at Y=2 and 8 m which cross closer to the edges of the structure.

Some caution is needed in interpreting strong continuous reflectors. Such a reflector is noted in the radargrams Y=0.25 to 1 m (Figure B4, Appendix B). In general, shallow discontinuous and cross-cutting reflectors are attributed to anthropogenic features, whereas long continuous reflectors usually are due to localized geologic conditions such as a distinct bedrock surface (i.e., no underlying alluvium) or an extensive patch of hard rock. In this case, the continuous reflector may be due to approaching and traversing over a turf wall at a small oblique angle.

Figure 6 displays two overlay time-slice images: b10, b11 (49 to 63 cm, Left) and b16, b17 (81 to 96 cm, Right). Comparison of the shallower image to the one from the 800 MHz survey at similar depth (Figure 5, Lower), shows good agreement in terms of delineating the narrow trench and the corresponding strong linear reflection to the north. As expected, the image generated from the 800 MHz survey yielded higher resolution. The deeper image shows a continuance of the linear reflection noted in the shallower image. In addition, similar to the observation of the images from the 800 MHz survey, there is a general east-west trending of lineations (see Figure C2).

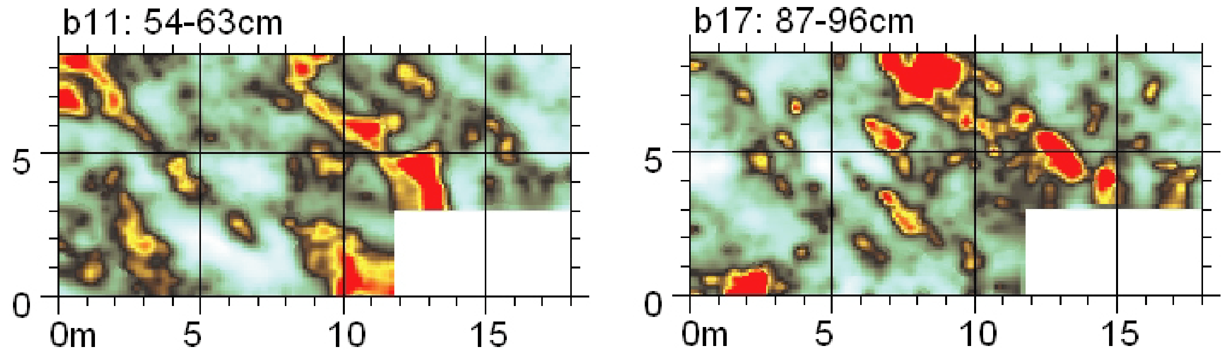

Figure 6: Time-slice images generated from 500 MHz survey. Upper: Overlay image for 49 to 63 cm bgs. Lower: Overlay image for 81 to 96 cm bgs.

4.0 SUMMARY AND RECOMMENDATIONS

Reconnaissance GPR surveys were conducted at the farm of Vatnsfjörður, northwest Iceland. The surveys were conducted to evaluate the usefulness of the method to delineate buried archaeological features of interest. Separate surveys were conducted using 800 and 500 MHz antennas. In general, the data quality was good, yielding maximum depths of penetration of approximately 0.5 m and 1 m bgs, respectively.

Based on comparison with results from limited shallow excavation conducted by the field school, the surveys were successful in delineating the presence of a central stone pavement within a turf structure. A narrow trench that cuts through the pavement was also delineated. In addition, turf walls and foundation stones may have been detected. Strong reflections from an area in the northern portion of the site infer the presence of rocks and possibly turf walls. If additional excavations are performed, the GPR results should be reevaluated in order to refine the interpretations and help guide the analysis of future surveys at the farm.

The future use of GPR at other sites on the farm should adopt similar recording parameters and field procedures as used here to ensure data quality. Future sites should be deturfed and transect spacing of 0.25 m should be selected. In addition, surveying in both orthogonal directions should be considered.

ACKNOWLEDGEMENTS

This work has been supported by National Science Foundation through awards 0453892 and 0731371. We thank John Steinberg, Douglas Bolender and Karen Milek for logistic support.

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APPENDIX A: OVERVIEW OF GROUND-PENETRATING RADAR

Ground-Penetrating Radar (GPR) is an active non-destructive geophysical method that provides shallow subsurface information. In GPR, electromagnetic (EM) energy is pulsed through a transmitter antenna that is towed along the ground surface. As the energy travels through the subsurface and encounters distinct changes in electrical properties—specifically, the relative dielectric constant (E_R)—a portion is reflected back to the ground surface. It is the two-way travel time of the reflected energy that is detected by a receiver antenna and is presented as a radargram, as schematically illustrated in Figure A-1.

Of all the available geophysical methods, GPR offers the highest possible resolution for subsurface imaging. The ability to resolved buried features, however, depends on the center frequency of the transmitted EM energy. Relatively higher frequencies (e.g., 500 megaHertz [MHz]) have greater resolving abilities but at the expense of less penetrating power as compared to lower frequencies (e.g., 250 MHz). The method works best in electrically resistive environments (e.g., desert environment with dry sandy soils). In general, electrically conductive environments can severely attenuate the pulsed EM energy. The presence water with high dissolved solids as well as clay and silt which retain water, even in minor amounts, can effectively limit the depth of penetration to less than a meter.

The use of GPR should be considered whenever the target of interest provides a distinct contrast in relative dielectric constant (air: $E_R = 1$, water: $E_R = 81$, dry soil: $E_R = 4\text{-}6$, wet soil: $E_R = 10\text{-}30$; rock/bedrock: $E_R = 5\text{-}8$) as compared to the surroundings and is sufficient in size to be detected. Typical targets include:

- buried stone walls and foundations;
- graves;
- site specific stratigraphy; and
- soil thickness/depth to bedrock.

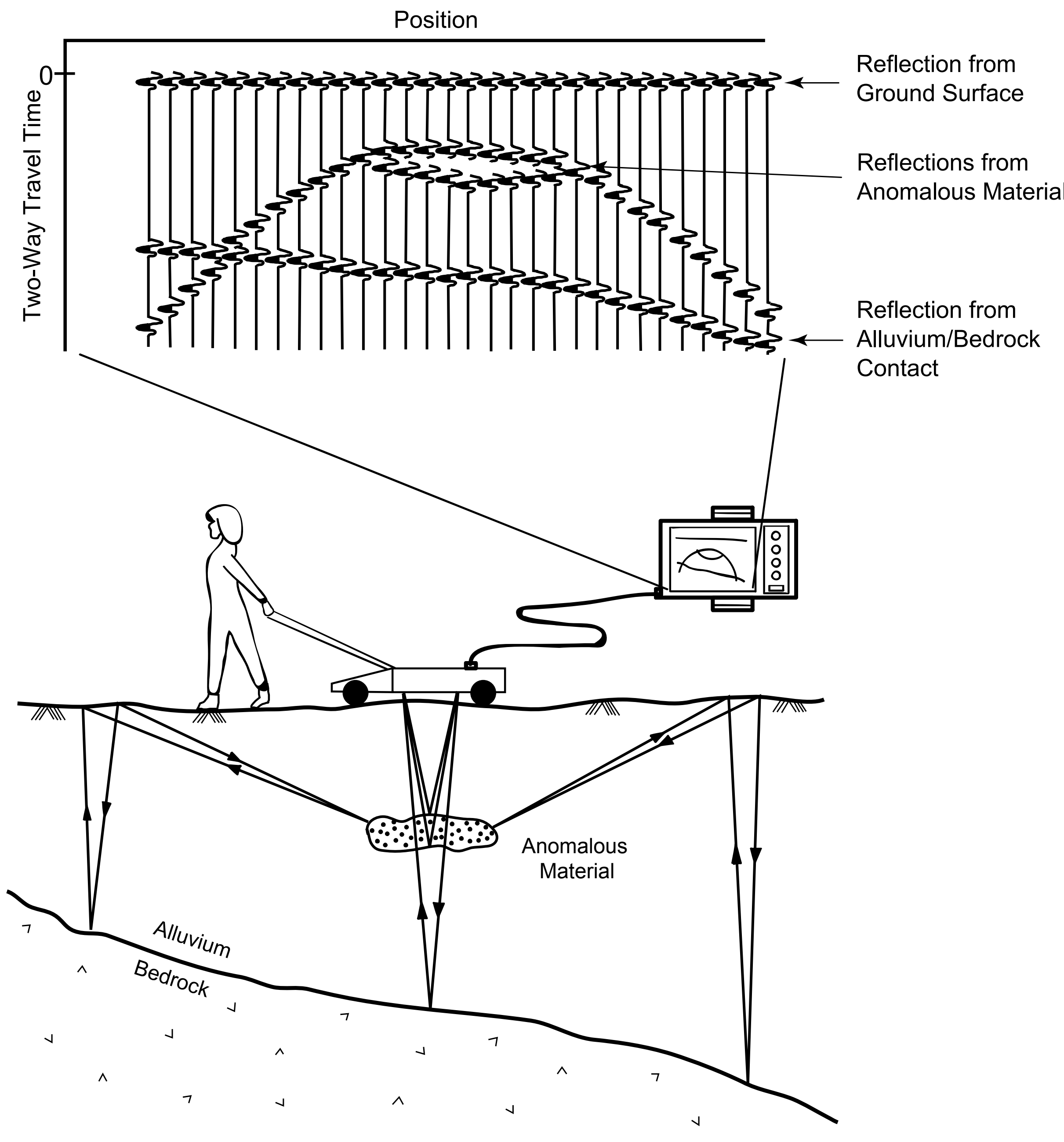

Figure A 1: Schematic Diagram Illustrating the Principles of GPR.

APPENDIX B: RADARGRAMS

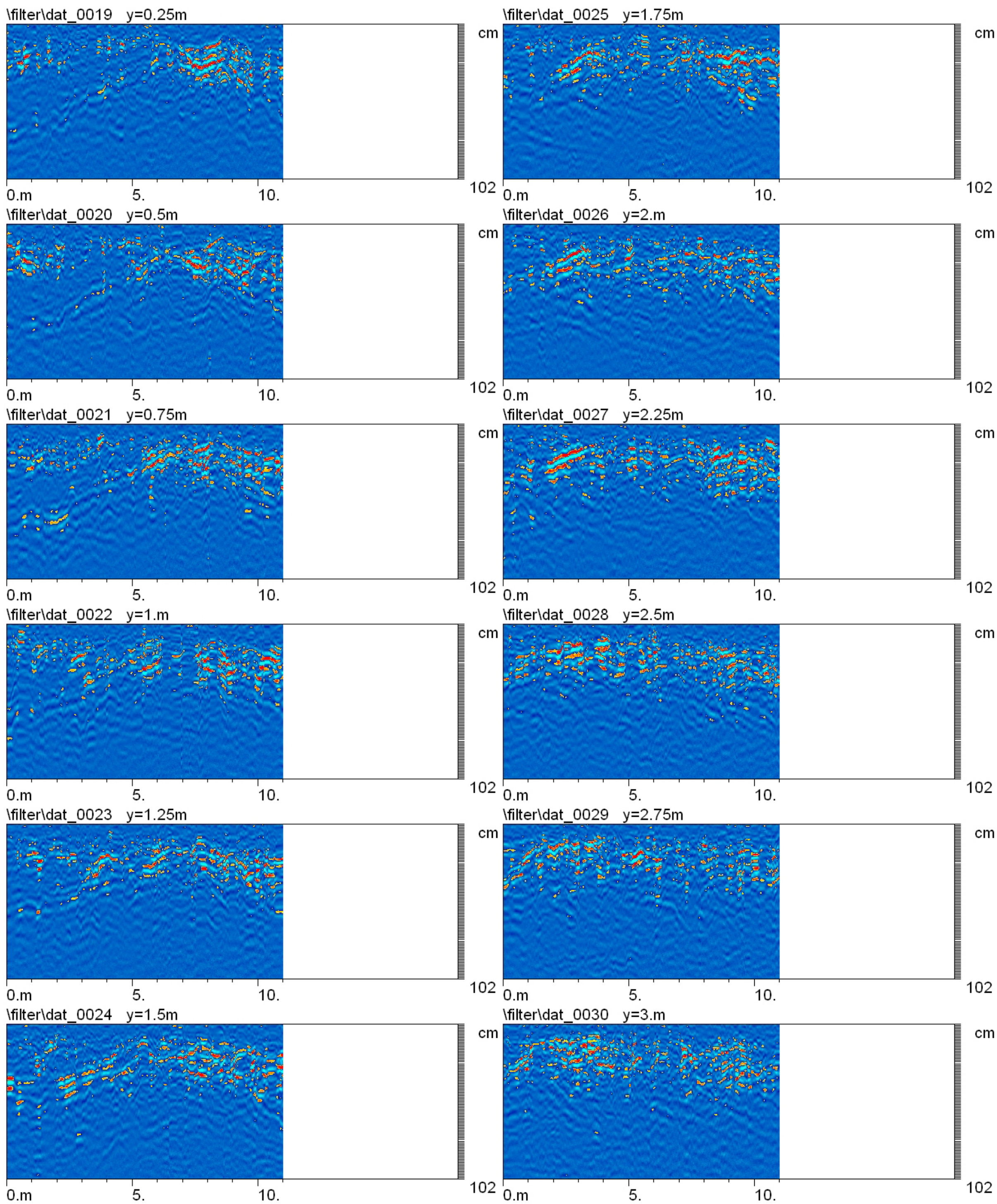

Figure B 1: Processed Radargrams for 800 MHz survey, Transects Y=0.25 to 3 m.

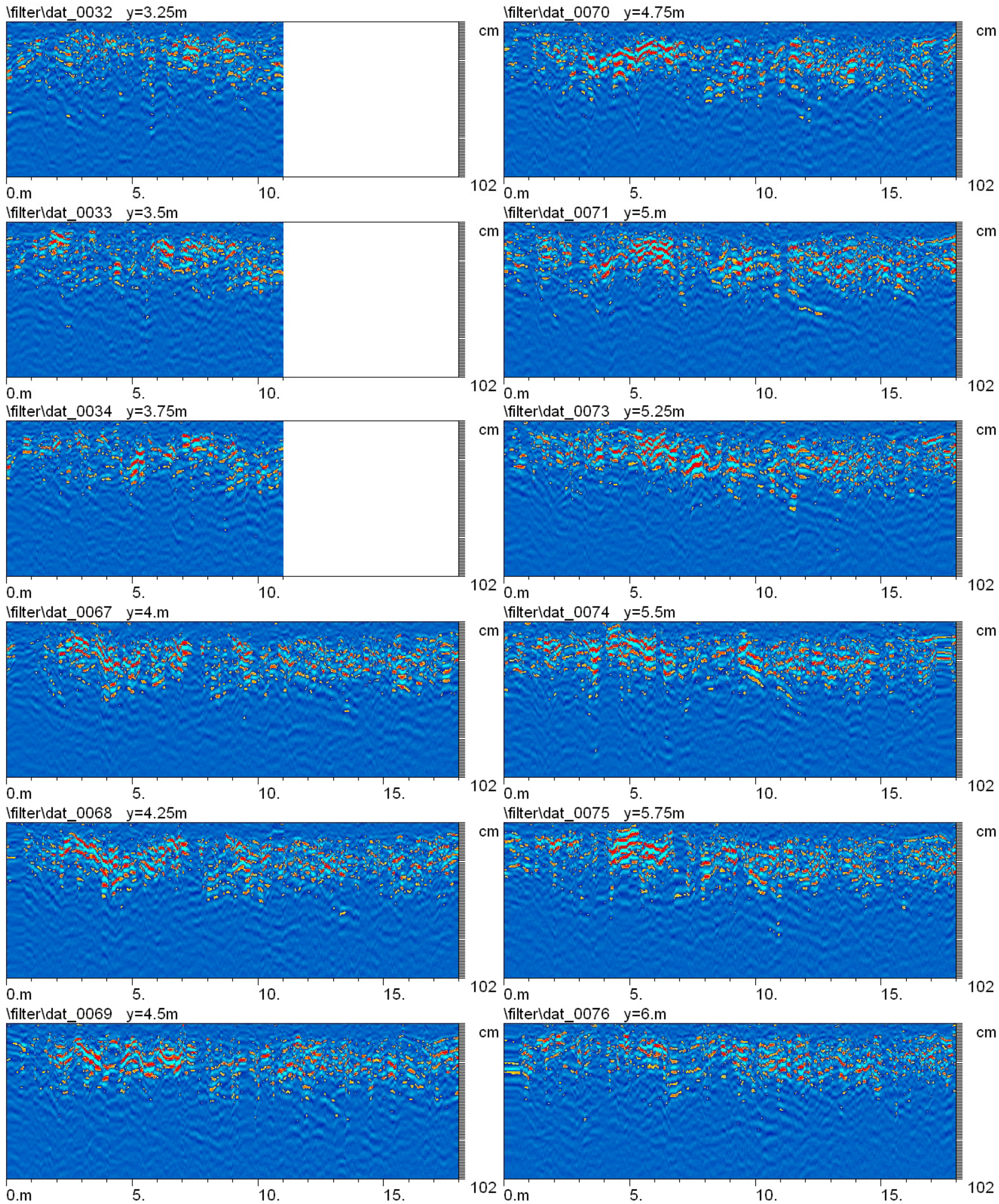

Figure B 2: Processed radargrams for 800 MHz survey, Transects Y = 3.25 to 6 m.

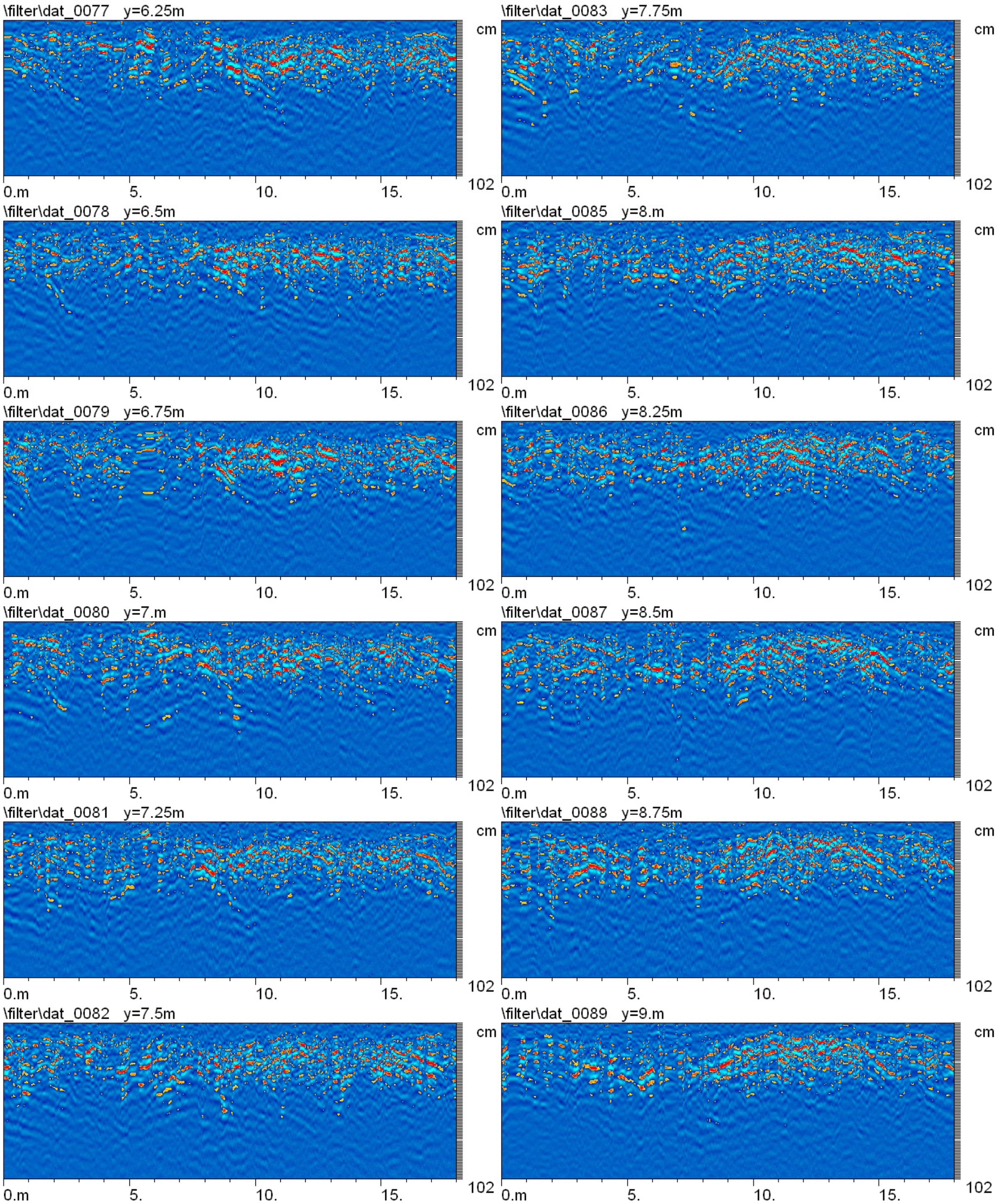

Figure B 3: Processed radargrams for 800 MHz antenna, Transects Y = 6.25 to 9 m.

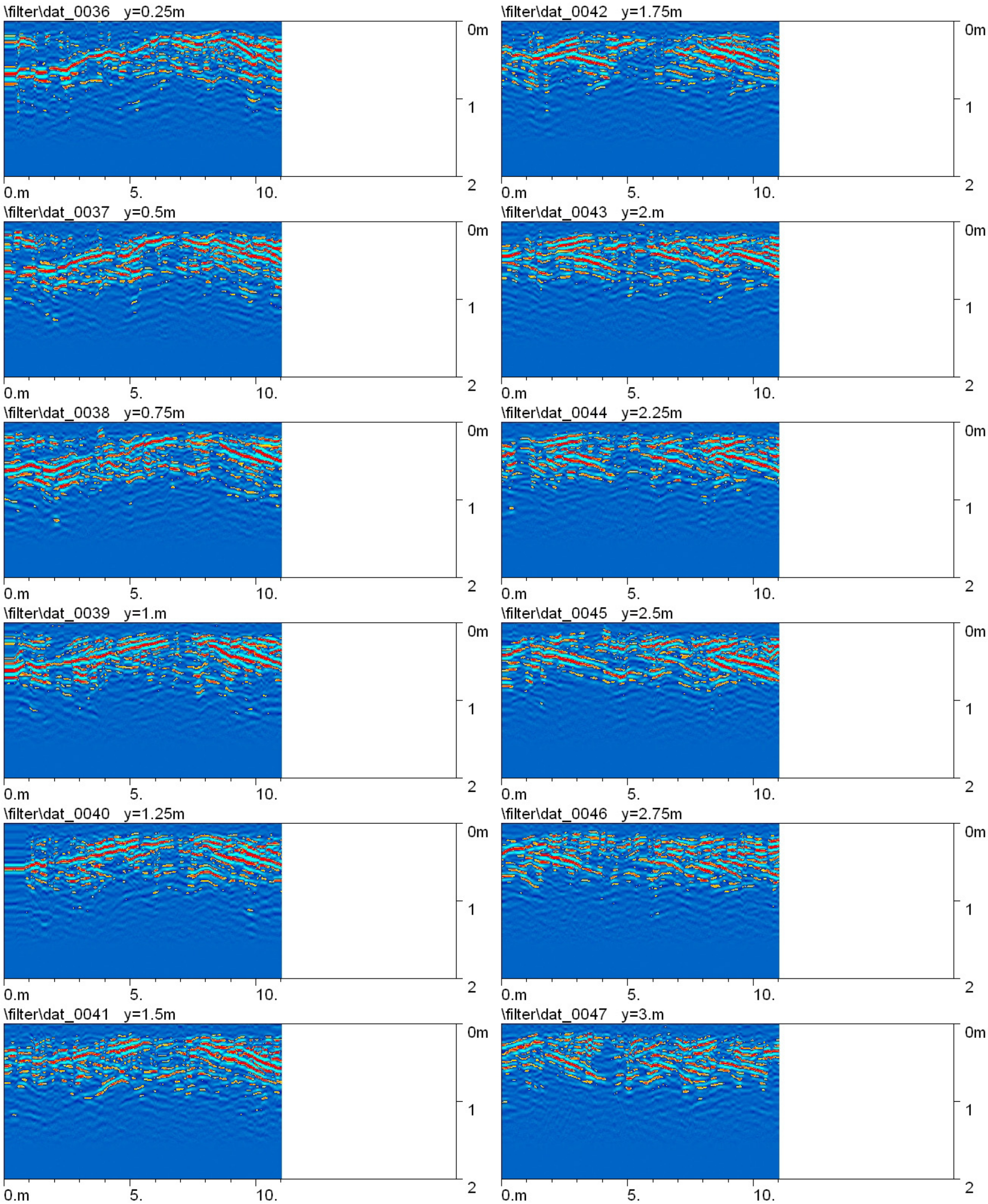

Figure B 4: Processed radargrams for 500 MHz survey, Transects Y = 0.25 to 3 m.

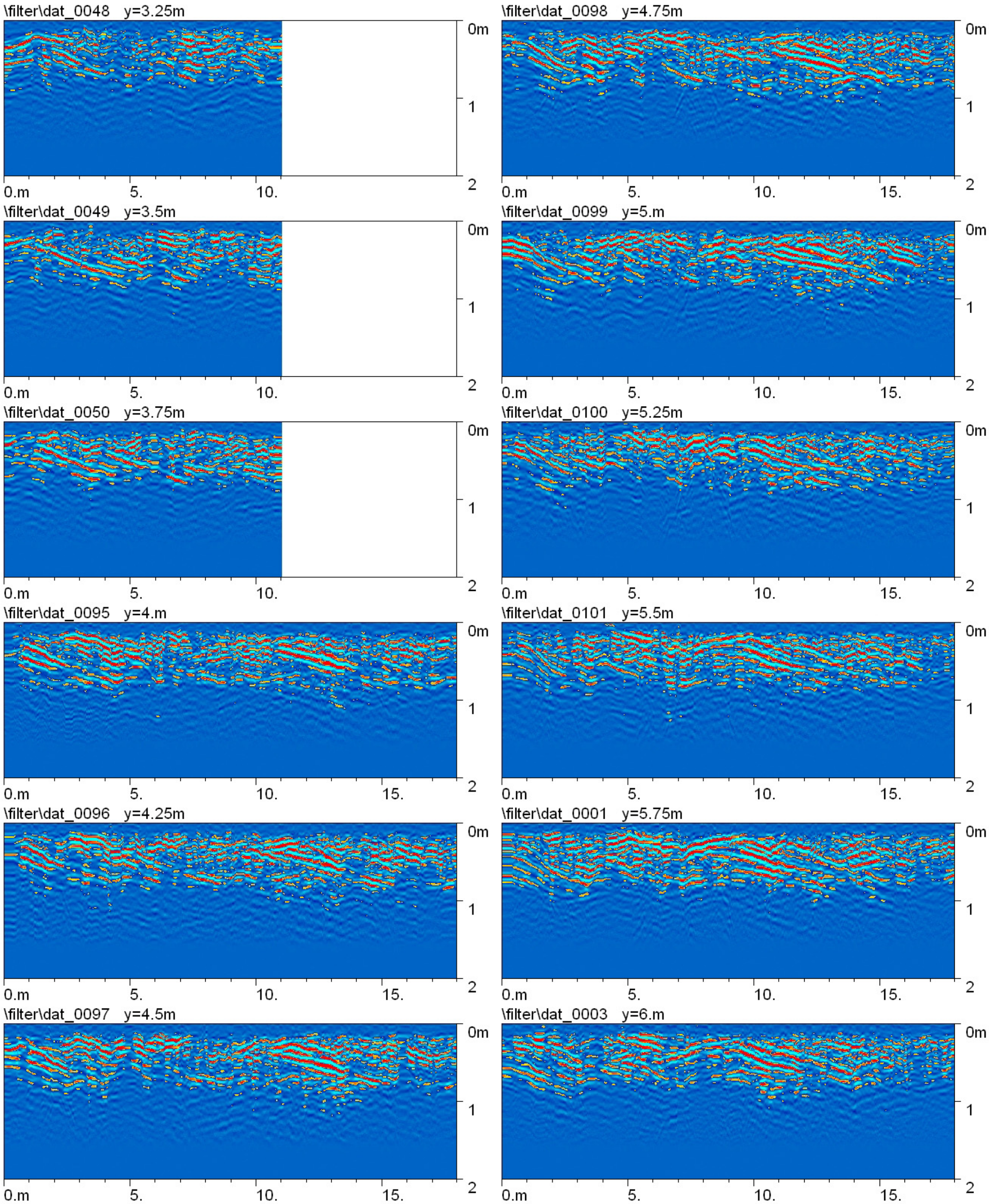

Figure B 5: Processed radargrams for 500 MHz survey, Transects Y = 3.25 to 6 m.

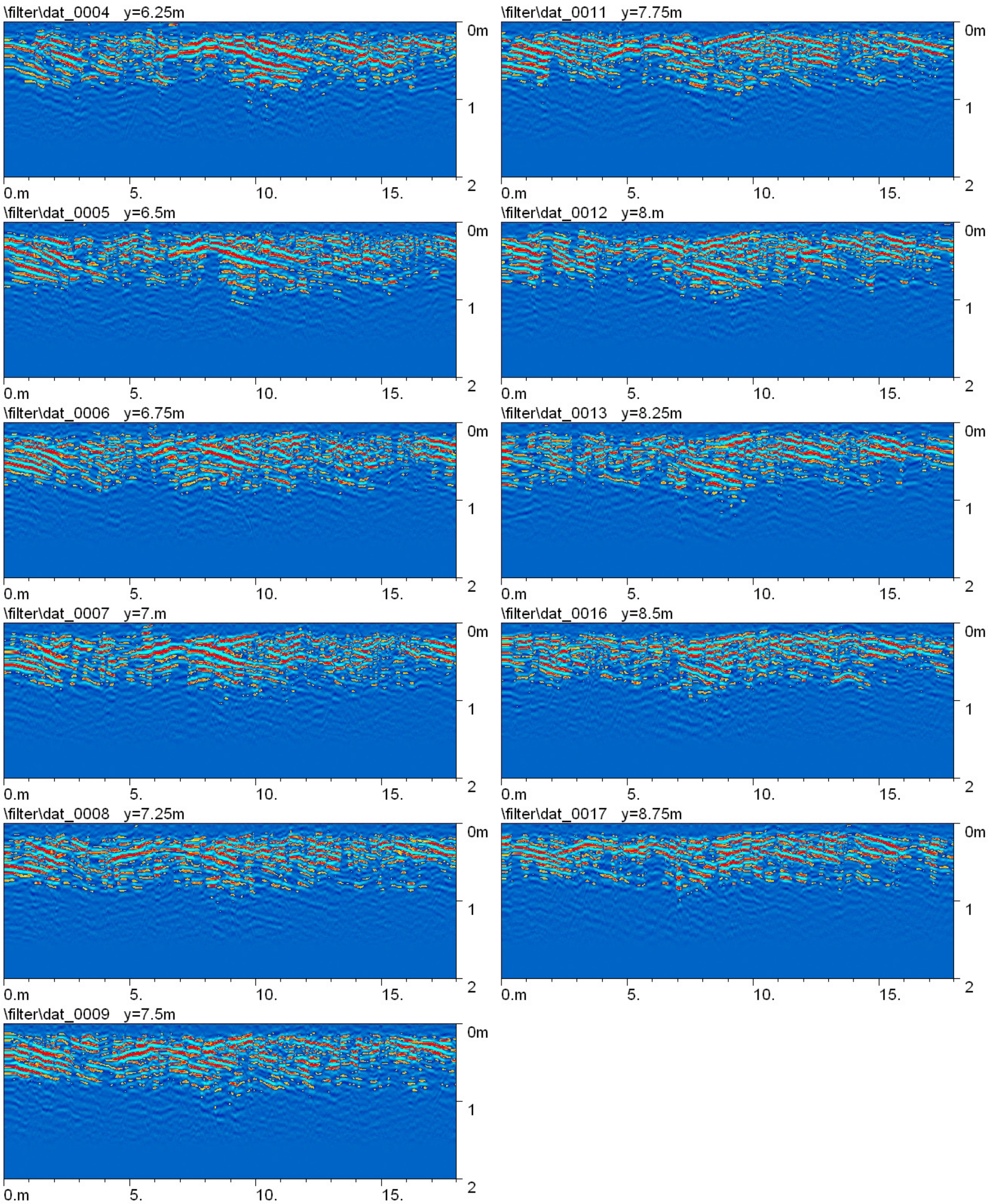

Figure B 6: Processed radargrams for 500 MHz survey, Transects Y = 6.25 to 8.75 m.

APPENDIX C: TIME-SLICE IMAGES

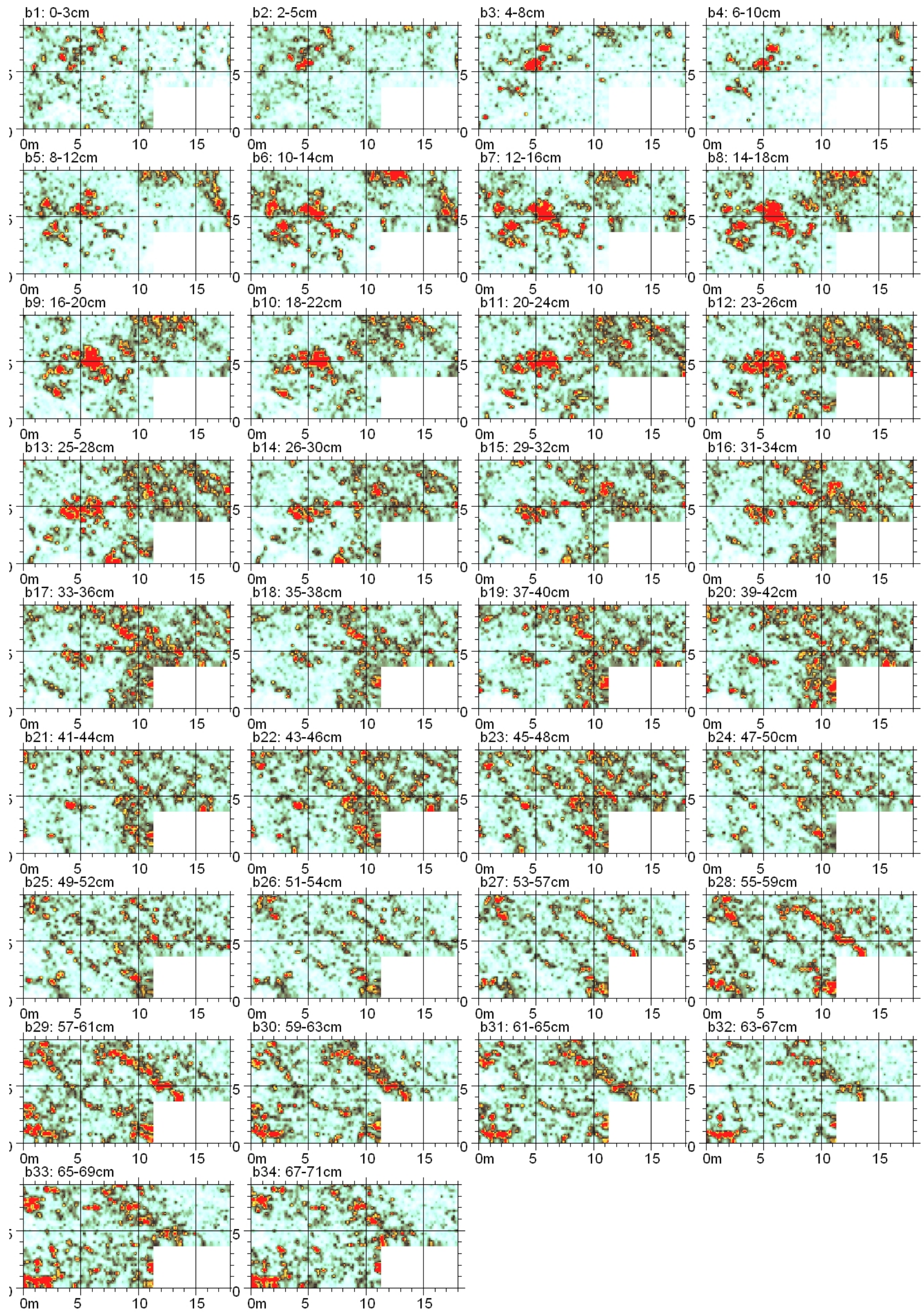

Figure C 1: Time-slice images for 800 MHz survey.

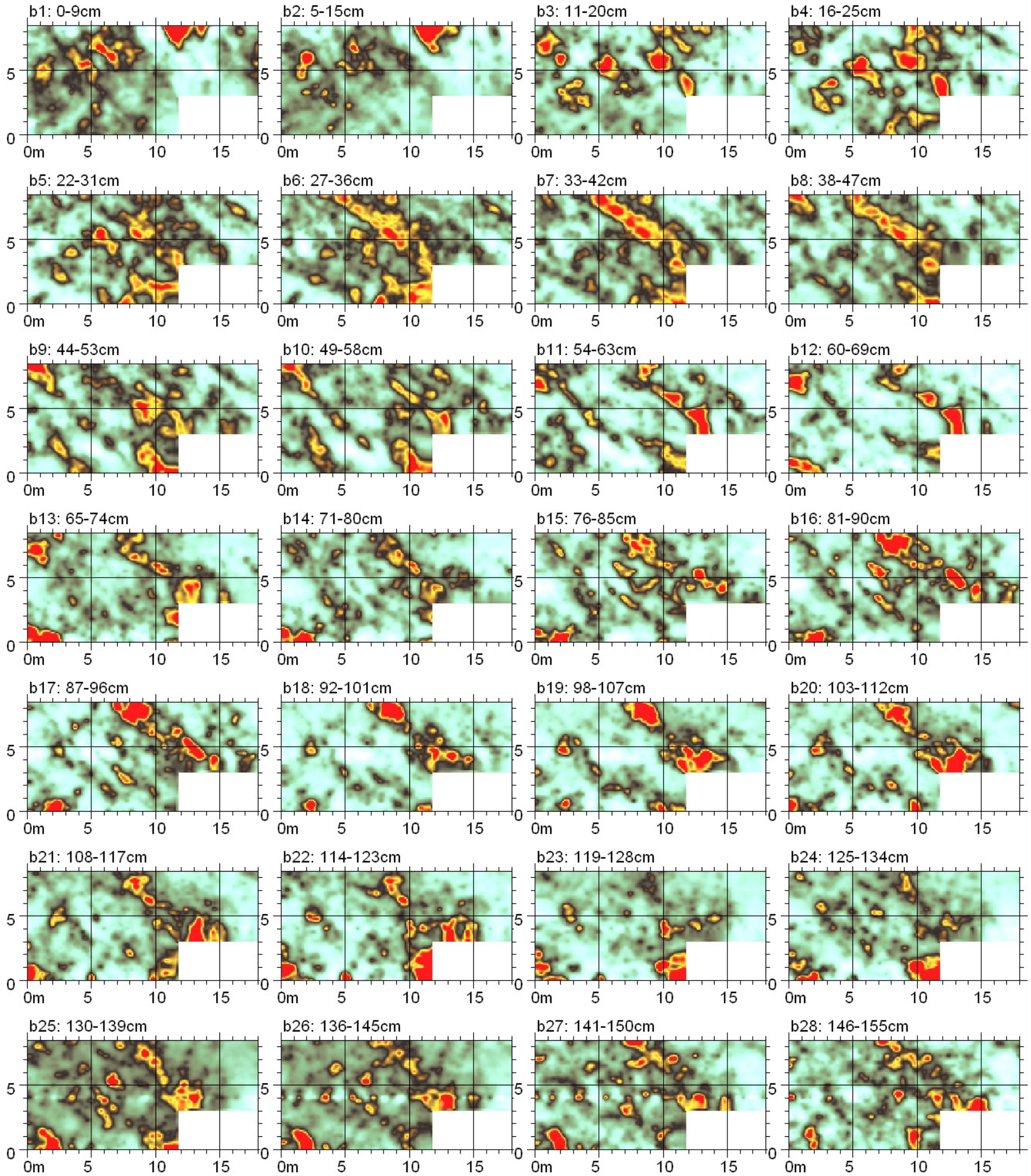

Figure C 2: Time-slice images for 500 MHz survey.