are partially obscured by other reflectors or where some interference effects are observed but a reasonable interpretation is still possible. These reflectors are consistent with locally discontinuous fractures or fracture zones. A score of 5 is assigned to reflectors that are degraded by severe interference, are difficult to observe at important angles, or are located where the electric-dipole component is missing or obscured. This type of reflector is consistent with chaotic fracture zones or faint reflectors in parts of the reflection record having low signal strength.

RESULTS OF BOREHOLE-RADAR REFLECTION LOGGING AT THE PROJECT SHOAL AREA

Omni-directional and directional-radar reflection logging was conducted using 60-MHz transmitting and receiving antennas in boreholes HC-1, HC-2, HC-5, HC-6, HC-7, and HC-8 at the Project Shoal Area, Churchill County, Nevada (fig. 1). Field logging parameters are listed in table 1. Figures 6 to 10 show (1) processed borehole-radar reflection logs; (2) lower-hemisphere equal-area stereo-nets showing the poles of the radar reflectors weighted by reflector length and combined quality score; and (3) logs showing the results of direct-wave velocity and amplitude analysis. Tables 2-6 give the location, orientation, length, and quality scores for the interpreted reflectors in each borehole.

The quality of the borehole-radar data ranged from very poor to good, with most data in the poor to fair range. Assuming that the radar equipment was functioning properly, the range in data quality can be attributed to the relatively low resistivity of the rocks underlying the PSA. As electrical resistivity decreases, attenuation of EM waves increases. Therefore, the radial penetration of the radar pulse into the rock is attenuated. In addition, as electrical resistivity decreases, a threshold is reached at which diffusive behavior dominates, and EM-wave propagation is no longer possible. The quality of the radar data collected from borehole HC-1 is so poor that it was uninterpretable; by contrast, the quality of the data from HC-6 and HC-7 was sufficient to map reflectors more than 10 m from the borehole.

Borehole HC-2

Radar reflection logging in borehole HC-2 was limited to omni-directional logging (table 1). Data quality was good (fig. 6A), with radial penetration exceeding 15 m. A total of 8 reflectors were interpreted from the reflection log (table 2). The estimated length of the reflectors imaged in HC-2 ranges from less than 3 m to more than 40 m. Interpreted dips range from about 15 to 80°, with a median dip of 60°. The direct-wave logs indicate the presence of low-velocity zones at depths of about 300 and 335 m (fig. 6B and 6C). Direct-wave amplitude and radial penetration increase below about 330 m, indicating that the electrical resistivity of the rocks below this depth increases.

Borehole HC-5

Radar reflection logging in borehole HC-5 included omni-directional and directional logging (table 1). The quality of the omni-directional and directional radar data was poor (fig. 7A), with few

Table 1. Radar reflection logging parameters, Project Shoal Area, Churchill County, Nevada
[x, data collected; --, no data collected; -, none]

Borehole number	Starting depth (meters)	Stopping depth (meters)	Step (meters)	Sampling frequency (megahertz)	Directional data collected	Omni-directional data collected	Comments
HC-1	339.25	400.00	0.25	1605.73	--	x	uninterpretable
HC-2	294.00	367.00	0.50	719.43	--	x	-
HC-5	390.00	592.00	0.50	917.60	x	x	-
HC-6	229.00	360.00	0.50	1376.36	x	x	-
HC-7	139.00	366.50	0.50	1310.82	x	x	-
HC-8	394.00	742.00	0.50	917.60	x	x	-

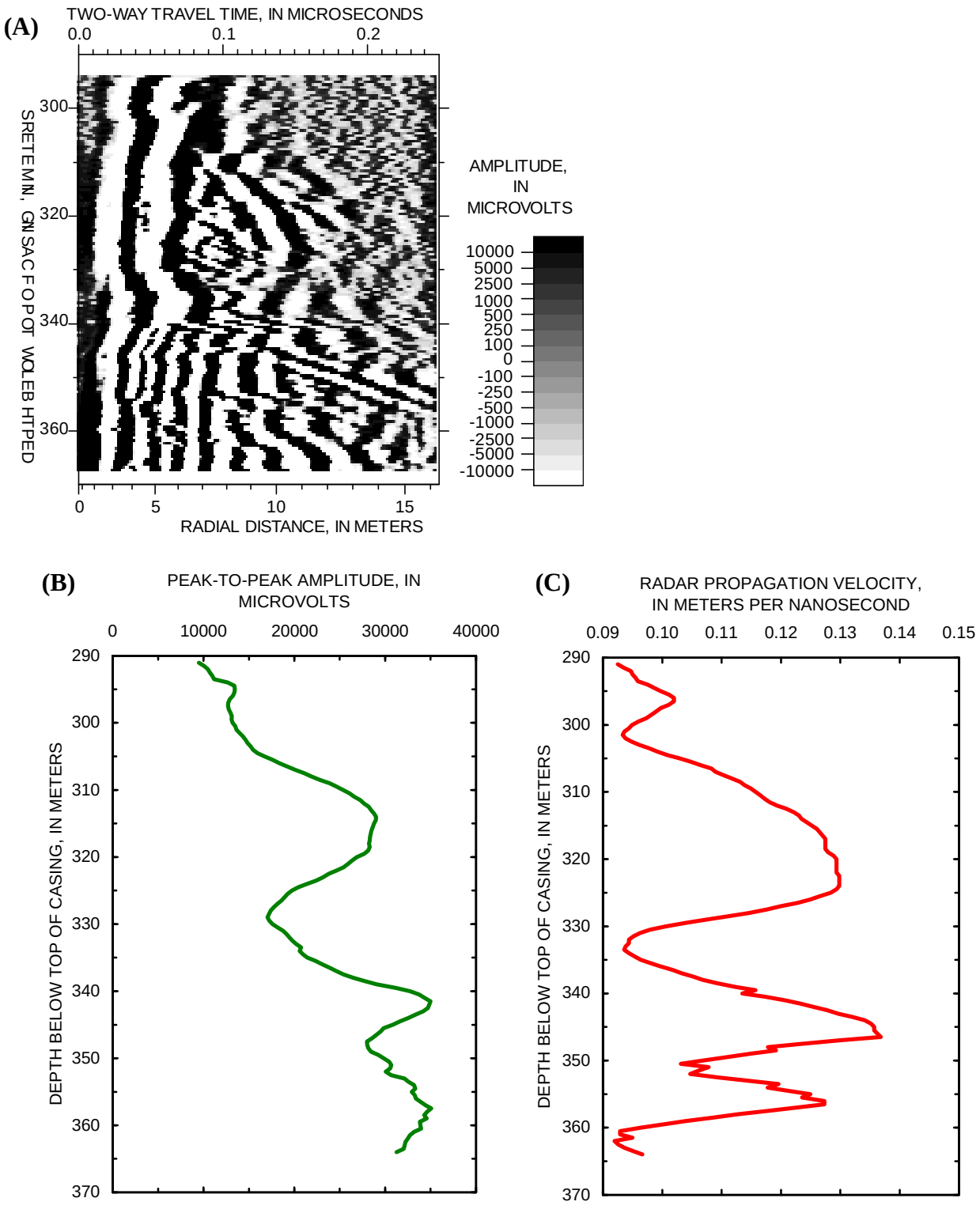

Figure 6. Radar reflection logging in borehole HC-2, Project Shoal Area, Churchill County, Nevada: (A) 60-megahertz electric-dipole omni-directional radar reflection log, (B) direct-wave amplitude log, (C) direct-wave radar velocity log.

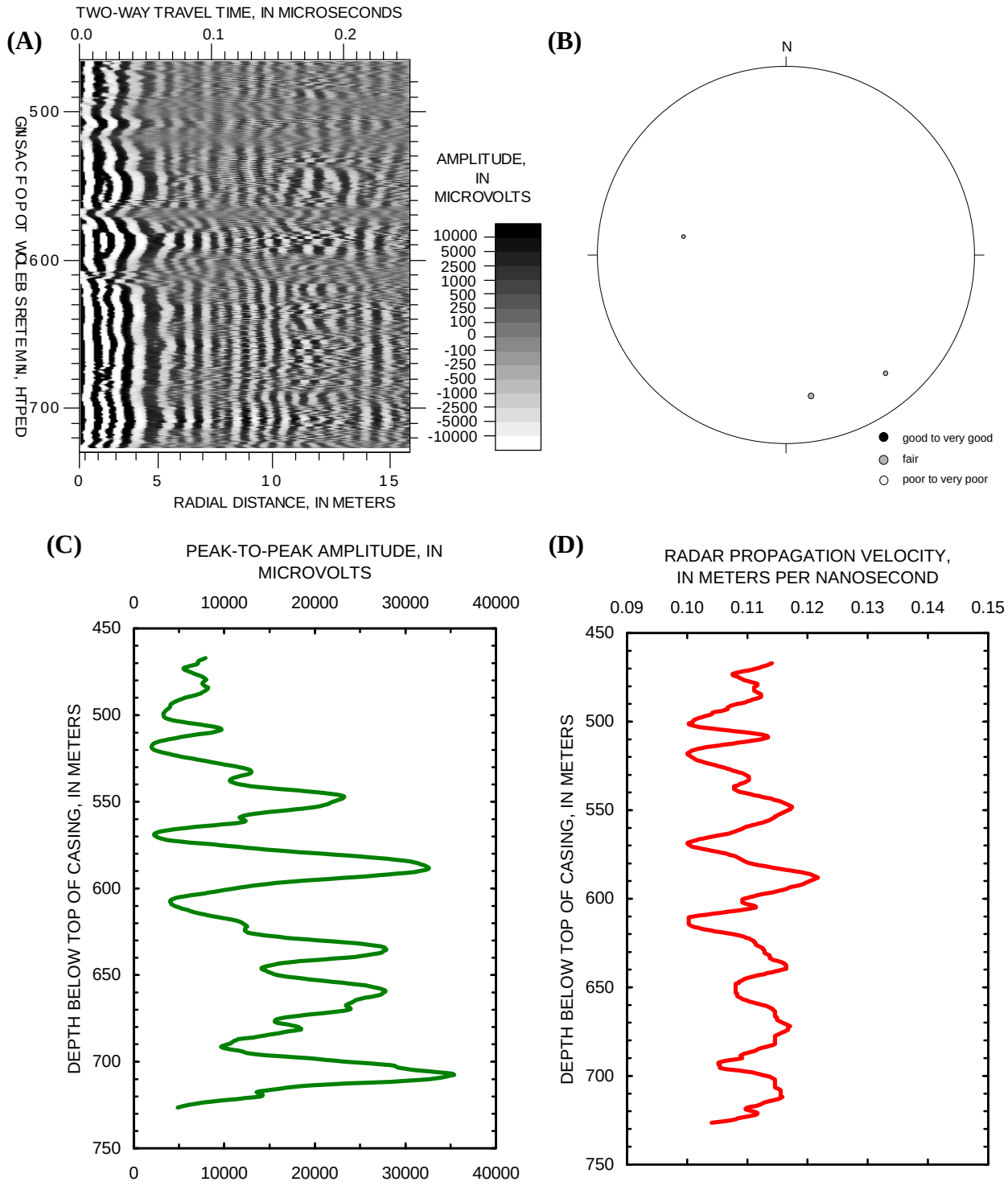

Figure 7. Radar reflection logging in borehole HC-5, Project Shoal Area, Churchill County, Nevada: (A) 60-megahertz magnetic-dipole directional radar reflection log, (B) lower hemisphere equal-area stereo-net showing poles of interpreted reflectors, (C) direct-wave amplitude log, (D) direct-wave radar velocity log.

Table 2. Planar reflectors interpreted from 60-megahertz radar reflection log, borehole HC-2, Project Shoal Area, Churchill County, Nevada

Depth from land surface (meters)	Dip (degrees)	Reflector continuity (1 = very good, 5 = very poor)	Estimated length of reflector (meters)	Comments
284.5	78	2	42.0	lower limb
299.5	62	4	24.0	lower limb
312.5	61	3	18.7	lower limb
318.5	52	4	8.7	lower limb
332.5	52	1	19.7	lower limb
333.2	15	3	2.6	lower limb
340.5	60	4	16.7	lower limb
354.4	60	5	8.7	lower limb

interpretable reflectors. Three reflectors were interpreted from the directional reflection log (table 3). Two reflectors strike west to southwest, dipping between 65 and 70°, one reflector strikes 10° east of north with a dip of 46°. These data are plotted on a pole-plane stereonet (fig. 7B). Each reflector is symbolized as a pole to the reflector plane, projected onto a lower-hemisphere, equal-area stereonet. The estimated length of the reflectors imaged in HC-5 ranges from less than 7 m to more than 40 m. The direct-wave logs indicate the presence of several minor low-velocity zones at depths of about 500, 520, 570, and 620 m. Direct-wave amplitudes generally increase with depth except near the low-velocity zones (figs. 7C and 7D).

Borehole HC-6

Radar reflection logging in borehole HC-6 included omni-directional and directional logging (table 1). The quality of the omni-directional and directional radar data was fair to good (fig. 8A). Five reflectors were interpreted from the directional reflection log (table 4). One reflector strikes to the northwest with a dip of 83°. Two reflectors strike southwest dipping at 71 and 80°, and two reflectors strike southeast with dips of 63 and 73°, respectively (fig. 8B). The median dip of the interpreted reflectors is 73°. The estimated length of the reflectors imaged in HC-6 ranges from less than 15 m to more than 140 m; the median reflector length is 37 m. The direct-wave logs indicate the presence of low-velocity zones above 100 m and below 300 m. An isolated low-velocity zone occurs at about 165 m. Direct-wave amplitudes generally increase with depth. The lowest direct-wave amplitudes occur above 100 m; amplitudes are fairly constant from 100 to 300 m except near the low velocity zone at 165 m (figs. 8C and 8D). It is interesting to note that direct-wave amplitudes increase below 300 m, whereas direct-wave velocities decrease over the same interval. This suggests that an increase in primary or secondary

Table 3. Planar reflectors interpreted from 60-megahertz radar reflection log, borehole HC-5, Project Shoal Area, Churchill County, Nevada

Depth from land surface (meters)	Strike (degrees)	Dip (degrees)	Reflector continuity (1=very good, 5=very poor)	Orientation confidence (1=very good, 5=very poor)	Estimated length of reflector (meters)	Comments
448.1	260	65	4	4	41.5	upper limb
464.2	230	70	4	4	21.0	upper limb
482.7	10	46	3	5	6.6	lower limb

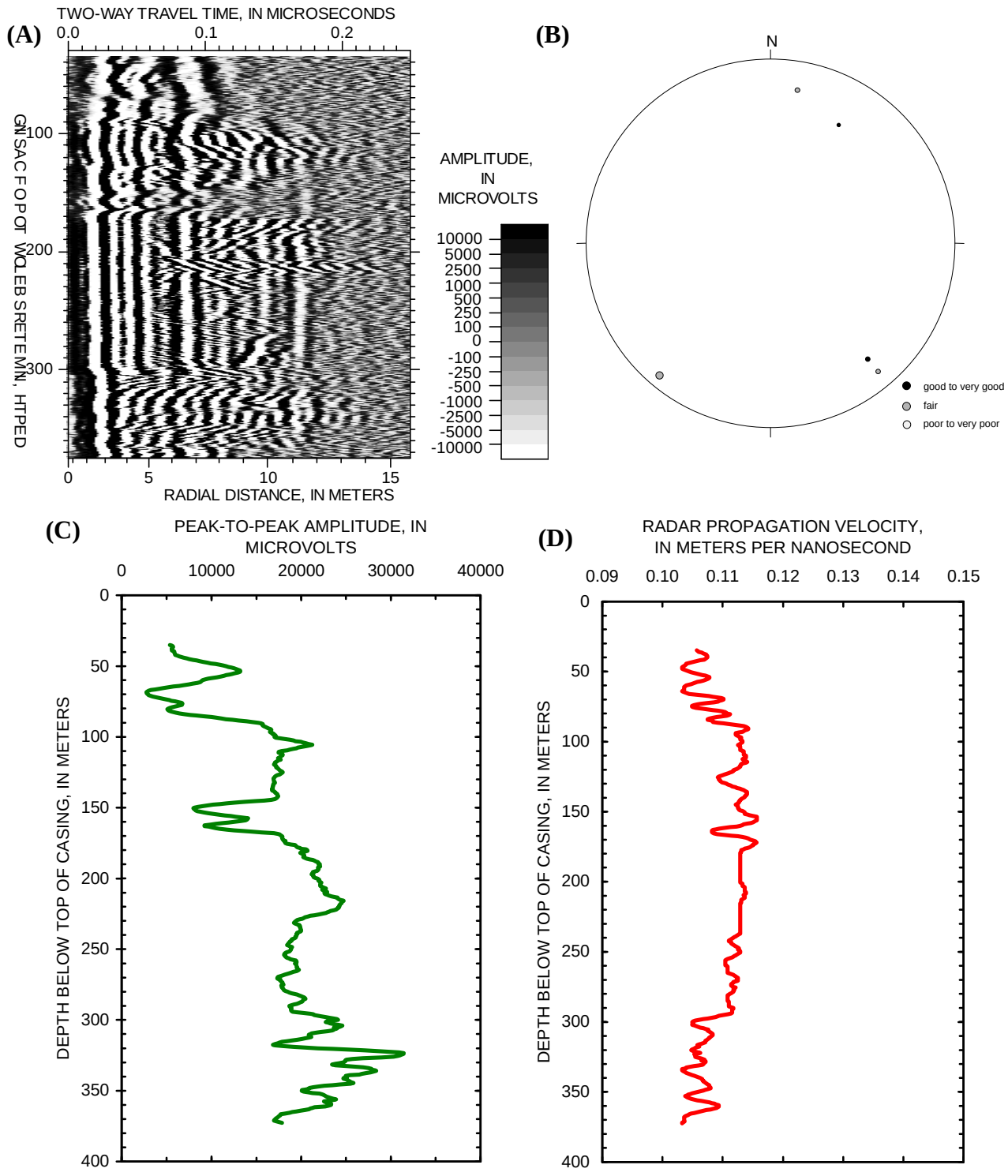

Figure 8. Radar reflection logging in borehole HC-6, Project Shoal Area, Churchill County, Nevada: (A) 60-megahertz magnetic-dipole directional radar reflection log, (B) lower hemisphere equal-area stereo-net showing poles of interpreted reflectors, (C) direct-wave amplitude log, (D) direct-wave radar velocity log.

Table 4. Planar reflectors interpreted from 60-megahertz radar reflection log, borehole HC-6, Project Shoal Area, Churchill County, Nevada

Depth from land surface (meters)	Strike (degrees)	Dip (degrees)	Reflector continuity (1=very good, 5=very poor)	Orientation confidence (1=very good, 5=very poor)	Estimated length of reflector (meters)	Comments
218.0	310	83	3	4	147.8	lower limb
257.7	120	63	3	3	14.4	crossing
270.4	230	80	4	4	34.7	crossing
271.6	230	71	2	3	34.5	lower limb
332.7	100	73	4	3	40.0	upper limb

porosity associated with a decrease in specific conductance of the ground water and (or) a change in mineral assemblage, is taking place in the rocks below 300 m.

Borehole HC-7

Radar reflection logging in borehole HC-7 included omni-directional and directional logging (table 1). The quality of the omni-directional and directional radar data was fair to good (fig. 9A). Fourteen reflectors were interpreted from the directional reflection log (table 5). The reflectors are clustered in three groups: (1) a northwest-southeast striking set with dips ranging from 73 to 84°; (2) an east-west striking set with dips ranging from 80 to 87°; and (3) a northeast-southwest striking set with dips ranging from 69 to 86° (fig. 9B).

The estimated length of the reflectors imaged in HC-7 ranges from less than 18 to more than 130 m; the median reflector length is 50 m. The direct-wave amplitude logs from HC-7 are remarkably similar to the logs from HC-6, when shifted upward 50 m. The direct-wave logs indicate that a continuous structure or structures could connect boreholes HC-6 and HC-7. The lowest velocities are present above 120 m and below 300 m. Isolated low-velocity zones occur at about 185 and 225 m. As in HC-6, direct-wave amplitudes generally increase with depth. The lowest direct-wave amplitudes occur above 120 m; amplitudes are fairly constant from 120 to 270 m except near the low-velocity zone at 220 m (figs. 9C and 9D). As in HC-6, direct-wave amplitudes increase below 300 m over the same interval that direct-wave velocities decrease, indicating an increase in primary or secondary porosity coupled with a decrease in the specific conductance of ground water, and (or) a change in mineral assemblage.

Borehole HC-8

Radar reflection logging in borehole HC-8 included omni-directional and directional logging (table 1). The quality of the omni-directional and directional radar data was fair (fig. 10A). Five reflectors were interpreted from the directional reflection log (table 6). All of the reflectors have strikes near north-south with dips ranging from 56 to 71° with a median dip of 63° (fig. 10B). The estimated length of the reflectors imaged in HC-8 ranges from less than 15 to about 28 m, the median reflector length is 19 m. The direct-wave logs indicate the presence of low-velocity zones near 630 and 710 m. Additional isolated low-velocity zones occur at about 655 and 665 m. Direct-wave amplitudes are generally constant over the logged interval except for decreases near the low-velocity zones (figs. 10C and 10D).

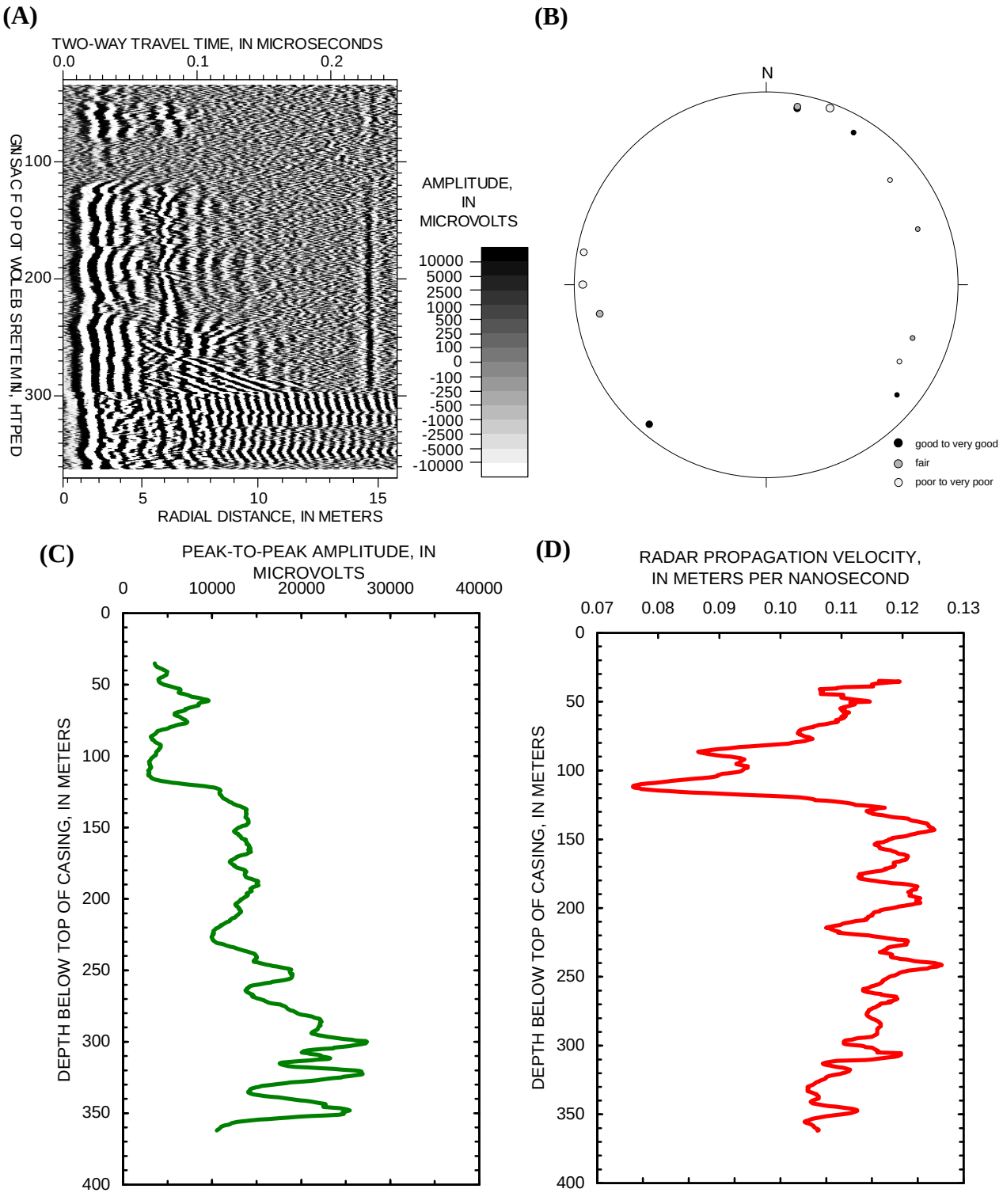

Figure 9. Radar reflection logging in borehole HC-7, Project Shoal Area, Churchill County, Nevada: (A) 60-megahertz magnetic-dipole directional radar reflection log, (B) lower hemisphere equal-area stereo-net showing poles of interpreted reflectors, (C) direct-wave amplitude log, (D) direct-wave radar velocity log.

Table 5. Planar reflectors interpreted from 60-megahertz radar reflection log, borehole HC-7, Project Shoal Area, Churchill County, Nevada
[n/a, not applicable - represents dipole only]

Depth from land surface (meters)	Strike (degrees)	Dip (degrees)	Reflector continuity (1=very good, 5=very poor)	Orientation confidence (1=very good, 5=very poor)	Estimated length of reflector (meters)	Comments
206.6	0	85	5	5	121.6	lower limb
219.7	10	86	5	5	80.1	lower limb
228.0	220	78	2	4	39.4	lower limb
282.7	200	70	3	4	32.6	crossing
310.4	160	73	4	4	32.7	crossing
318.6	n/a	74	5	5	17.5	lower limb
329.1	100	82	2	2	72.1	lower limb
340.1	100	83	3	4	60.8	lower limb
364.2	120	80	3	2	40.1	lower limb
424.9	310	84	3	2	80.2	upper limb
426.1	350	77	4	4	63.5	crossing
451.4	140	73	4	5	29.1	upper limb
468.2	210	69	5	4	21.3	upper limb
540.2	110	87	4	5	133.6	upper limb

Table 6. Planar reflectors interpreted from 60-megahertz radar reflection log, borehole HC-8, Project Shoal Area, Churchill County, Nevada

Depth from land surface (meters)	Strike (degrees)	Dip (degrees)	Reflector continuity (1=very good, 5=very poor)	Orientation confidence (1=very good, 5=very poor)	Estimated length of reflector (meters)	Comments
381.7	350	56	5	5	28.3	lower limb
406.8	170	63	5	5	14.2	lower limb
419.9	190	71	2	4	18.3	lower limb
426.6	190	58	3	4	19.4	crossing
434.6	180	63	4	4	23.6	crossing

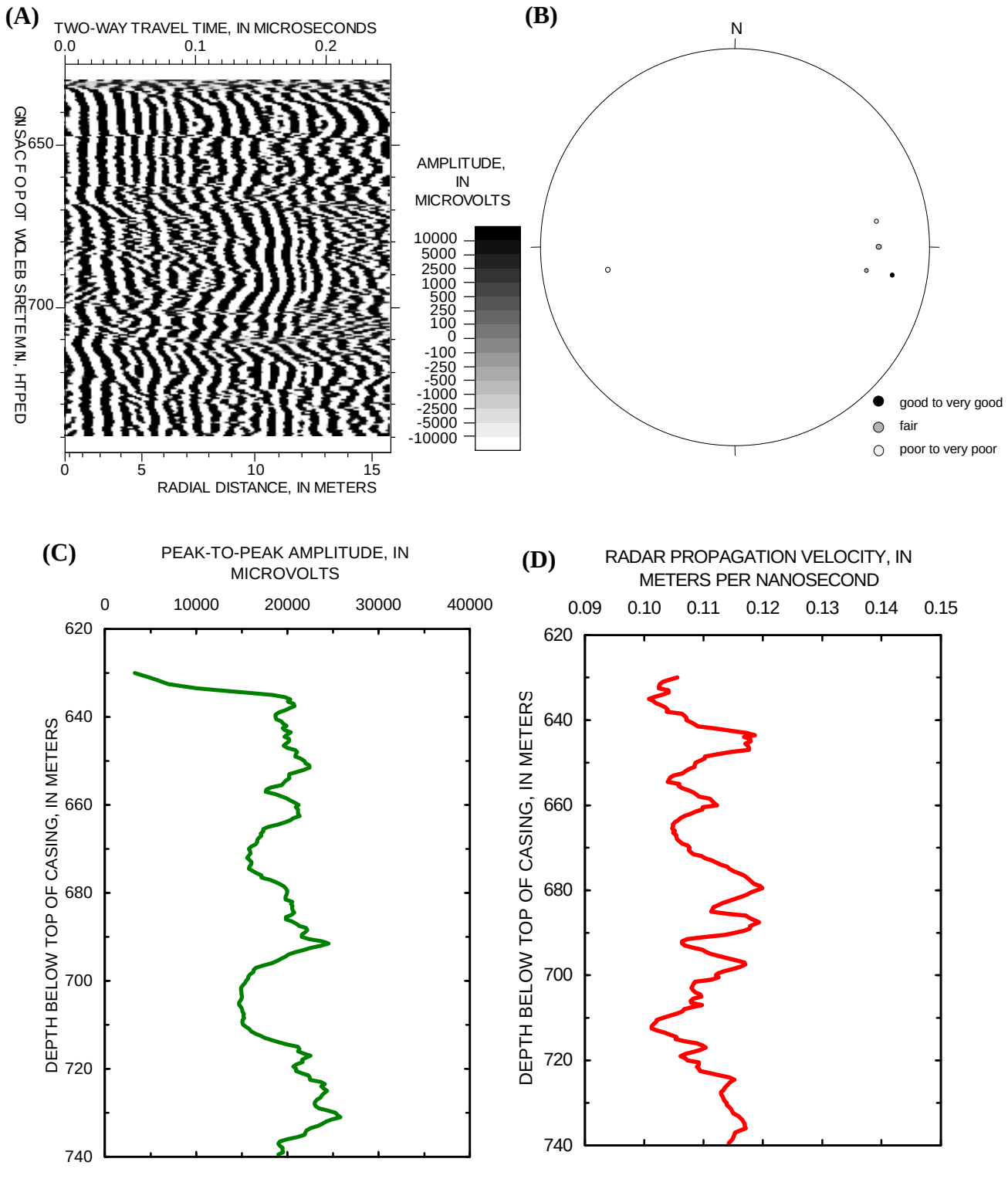

Figure 10. Radar reflection logging in borehole HC-8, Project Shoal Area, Churchill County, Nevada: (A) 60-megahertz magnetic-dipole directional radar reflection log, (B) lower hemisphere equal-area stereo-net showing poles of interpreted reflectors, (C) direct-wave amplitude log, (D) direct-wave radar velocity log.