COCORP DEEP SEISMIC PROFILES ACROSS THE WIND RIVER MOUNTAINS, WYOMING

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INTRODUCTION

The origin of basement uplifts in the Laramide province has long been a major controversy in the tectonics of the western United States. Surface geology on a regional scale (Figure 1) has emphasized the diversity of fault trends and orientations of uplifts, resulting in interpretations favoring dominantly vertical uplift (Prucha et al, 1965; Stearns, 1971). Others working with the same data base have concluded that horizontal compression was more important (Berg, 1962; Blackstone, 1963; Sales, 1968). Because the Laramide deformation occurred 1,000 to 1,500 km (621 to 932 mi) from the coeval plate margin along the western margin of North America, resolution of this controversy has important implications for the dynamics of plate interactions and the deformation of continental crust.

The Wind River Mountains are the largest Laramide uplift in Wyoming. The structure is a northwest trending, asymmetric feature, approximately 220 km (137 mi) long and 70 km (43 mi) wide. On the northeast side, Paleozoic shelf sediments, resting unconformably on Archean crystalline basement, dip gently to the northeast into the Wind River basin. The southwest side of the uplift is a northeast-dipping reverse fault, as shown by surface mapping, industry and government boreholes, and industry seismic reflection data (Berg, 1962; Royse et al, 1975). The minimum vertical structural relief between the Precambrian in the high peaks of the Wind River Mountains and the bottom of the Green River basin to the southwest is about 13 km (8 mi).

The Archean rocks consist of migmatites from deeper crustal levels now exposed in the core of the uplift north of the COCORP profiles, and at the south end in the vicinity of the seismic lines, granitic intrusions into gneisses and schists that represent shallower levels of the crust. These supracrustal rocks, which include iron formation, metaandesite, and metagraywacke, are steeply dipping and strongly folded. Condie (1972) suggested that an Archean greenstone belt and suture zone is located in the region beneath the COCORP profiles.

COCORP seismic reflection profiles (Figure 2) were collected across the southeast end of the Wind River Mountains in the vicinity of South Pass during 1976 and 1977. Three separate sections, lines 1, 1A, and 2, in aggregate form 168 km (104 mi) of 24-fold common depth point (CDP) data. Unfortunately, crosslines have not been shot, preventing a unique interpretation. On line 1, a 48-channel recording system and 134 m (83 mi) station spacing were used, whereas on line 1A and 2 a 96-channel system and 100 m (62 mi) station spacing were used. Listening and recording times were adjusted to give 30 sec records on line 1, and 20 sec records on lines 1A and 2. Five in-line vibrators used a sweep frequency of 8-32 Hz, with 16 sweeps per vibrator point. Standard data processing techniques were applied. The resulting unmigrated seismic section is shown on Figure 3 with an interpreted line drawings on Figure 4. The descriptions and interpretations of the COCORP data presented here are based on more detailed accounts by Smithson et al (1977, 1978) and Brewer et al (1980).

STRUCTURE OF THE WIND RIVER MOUNTAINS

The COCORP results appear to demonstrate that the reverse fault bounding the Wind River Mountains dips eastward beneath the mountains at approximately 35 to 40°, and extends to at least 25 to 30 km (15 to 18 mi) depth within the crust as a relatively discrete fault zone. The fault appears as a relatively planar structure with little evidence of significant steepening with depth. Thus horizontal compression was the dominant mechanism, producing 13 km (8 mi) of vertical separation and 26 km (16 mi) of horizontal separation. Determination of the exact amount of displacement is difficult for two reasons. Though predictive deconvolution with an operator of 560 msec was useful in removing some multiple energy, autocorrelation studies show that significant multiple reflections, generated within the sediments of the Green River basin, may remain. Events "A" (identified on Figure 4) appear to be within the basement but may actually be multiples from the overlying sediments. Although the top of crystalline basement is probably between 4.0 and 4.5 secs (Figures 3 and 4), its exact depth cannot be determined. The second reason is related to the deterioration of data quality immediately northeast of the surface position of the Wind River fault (vibrator point VP 250, line 1). Precambrian rocks in the upper plate at the toe of the thrust are intensely crushed and broken. Inadequate velocity control or lack of penetration in the deformed basement rocks may be responsible for the poorer reflection quality between VPs 250 and 310. Even so, a few of the strongest reflections of sediments within the Green River basin can be traced northeastward into and through the zone of poor data quality (at 2.0 to 2.5 secs, and at 3.0 to 3.5 secs), demonstrating that a near-vertical fault is not present there. Northeast of VP 310, there are excellent reflections from the Wind River thrust, and probably from some of the sediments beneath the overhang as well. However, it is difficult to identify the actual footwall cutoff of the sediment basement-sediment contact. "B" of Figure 4 shows a possible location for the cutoff.

The geometry of reflection events within the footwall beneath the overhang probably reflects velocity pullup due to the shorter traveltimes through higher velocity basement rocks at the surface. In the geologic section on Figure 5, this effect is corrected. Even though the events are pulled up to the northeast, many appear to roll over approaching the thrust. The rollover must correspond to real geologic structure and is shown on the depth section as a down-bending of Green River basin sediments near the thrust zone. In general, structure in the sediments directly beneath the thrust is probably complex, and may include overturning and imbrication.

The reflections that characterize the Wind River thrust are complex. Between 1 and 2 secs, a simple two-cycle event projects to the buried surface trace. Between 2 and 6 secs, reflections are less distinct but are nearly as continuous. The events in this interval form a broader zone, approximately 0.5 secs wide (along a single CDP). Events from in or near the fault zone appear to bifurcate between 6.5 and 9.0 secs, forming two distinct, subparallel bands, in total spanning a vertical width of 1.0 sec. Distinct fault zone reflections disappear beneath 9.0 secs northeast of VP 375 on line 1A. However, events with similar dip between 10.5 and 12.0 secs lie on the projection of the fault zone on the end of line 1A and on the beginning of line 2. The nature of these last events is in some doubt.

Although they cannot represent simple multiples from the overlying sedimentary section, some complex peg-leg multiples cannot be ruled out.

Thus, the Wind River thrust can be extended with relative certainty to approximately 27 km (16.7 mi) within the crust, and may possibly be traceable to as deep as 36 km (22 mi). The position of Moho is unknown in this area, but both to the north and southwest it is about 40 km (24.8 mi; Prodehl, 1970; Braile et al, 1974). Reflections from the fault zone are most distinct where basement rocks are thrust against sediments, but can also be traced where basement is faulted against basement. Below 18 to 20 km (about 12 mi), the character of the fault zone reflections changes and may represent a widening of the fault zone in response to different deformation mechanisms within the lower crust. This change may be related to a complex series of events in the upper plate (C′, Figure 4), which may in turn correspond to similar events in the lower plate (C, Figure 4; Smithson et al, 1978). The nature of C and C′ are unknown, but they may be diffractions or reflections from complex Precambrian structures.

The maximum migrated dip of the thrust is approximately 38°. This dip, however, is only apparent because logistical considerations prevented shooting of planned crosslines in the region, which would have provided important three-dimensional control. Changes in direction of lines 1, 1A, and 2 appear to be insufficient to indicate true dips. Based on the angle at which the seismic survey crossed the surface trace of the fault, the true dip is probably no greater than about 45°.

On line 1 between VPs 100 and 185, a broad gentle flexure known as the Pacific Creek anticline is clearly visible within the sediments of the Green River basin. The anticline is bounded on its west side by a fault that probably does not extend much higher into the sediments than about 3.0 secs. The fault can be identified by the crossing diffraction tails that originate at truncated beds on either side of the fault. Similar diffractions are not present on the east side of the anticline. The probable orientation of the fault within the basement is shown as a dotted line on Figure 4. This apparent dip is approximately parallel to the Wind River thrust located just to the northeast.

On the northeast side of the Wind River Mountains, the dip slope of Phanerozoic sediments of the Wind River basin is deformed by some northeast dipping thrusts that are responsible for several small uplifts in the basin. Coverage was irregular because numerous skips were required by the oil-producing activity in this region. Though the individual faults were not imaged, event "E" on Figure 4 may correspond to a reflected refraction from the nearest fault. A strong event between 5 and 6 secs beneath the Wind River thrust may also represent a reflected refraction from the thrust although the refracting layer in this case is not clear.

CONCLUSIONS

The COCORP profiles across the Wind River Mountains shed important new light on a major problem of regional tectonics: the origin of the Laramide uplifts. The conclusion that the uplifts are a result of horizontal compression affecting the entire thickness of the crust must be incorporated into plate tectonic models for their origin. The recent models that have proposed nearly flat subduc-

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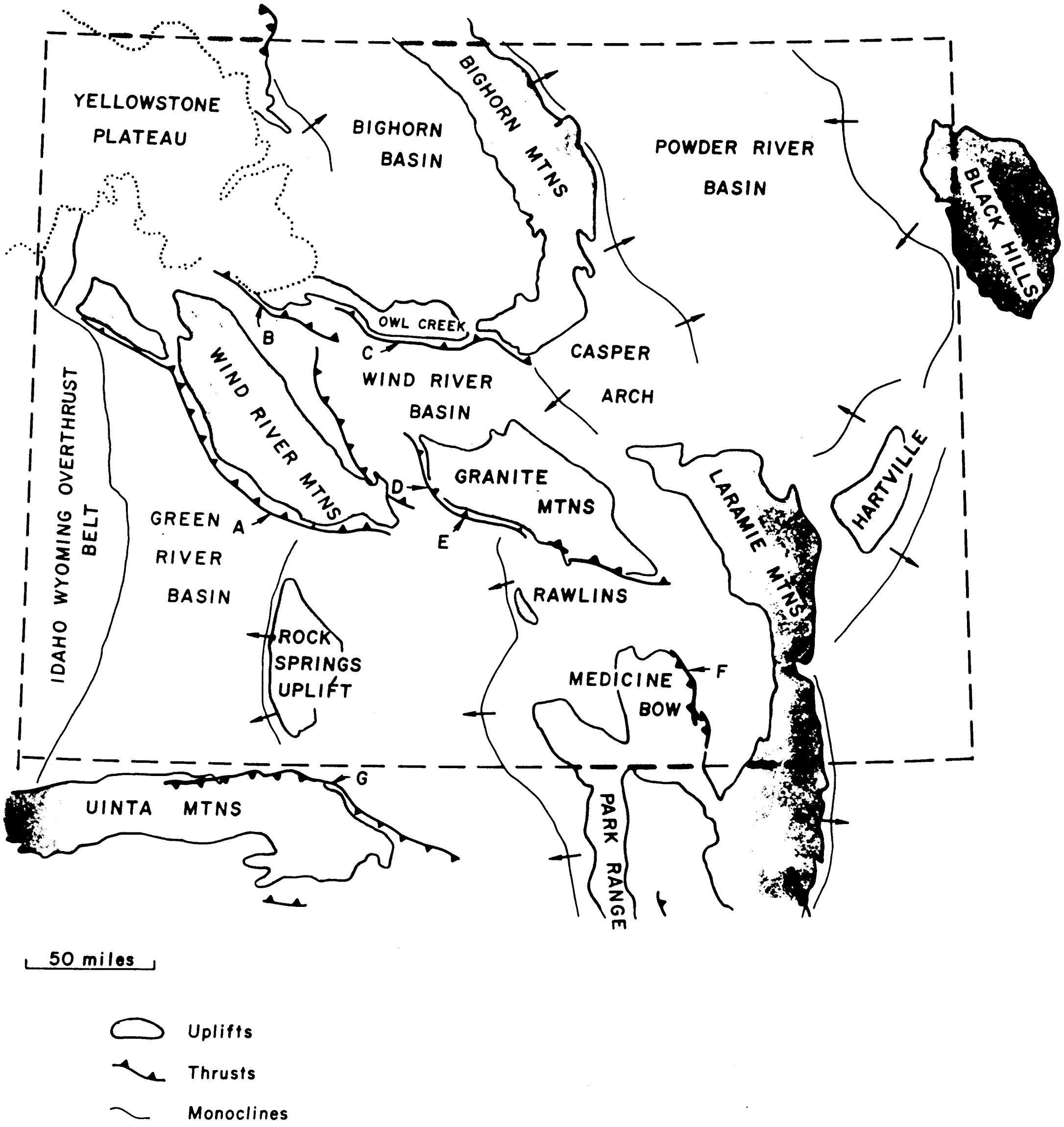

Figure 1: Tectonic map showing basement uplifts in Wyoming.

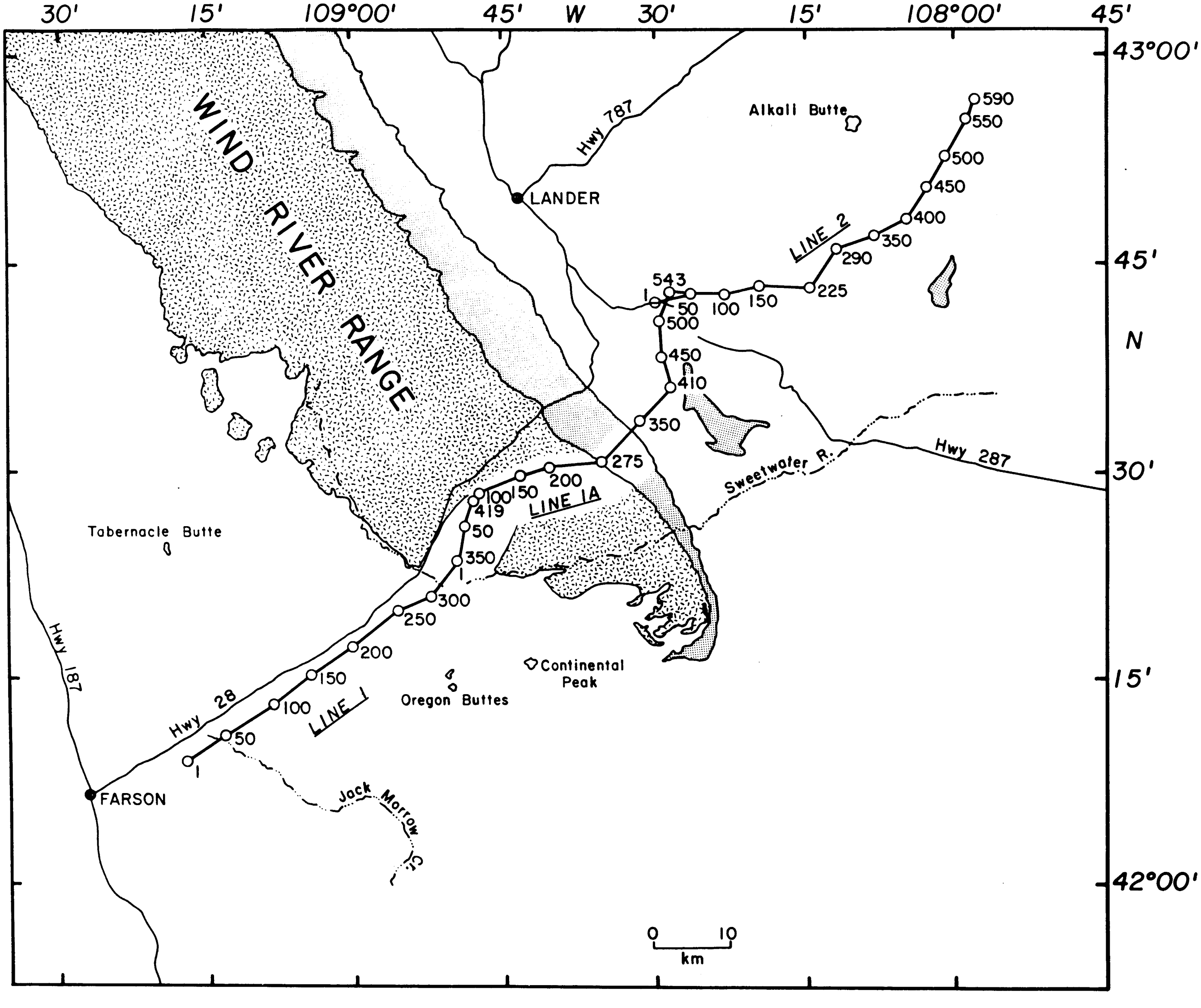

Figure 2: Location map of COCORP seismic reflection profiles 1, 1a, and 2 traversing the southeast end of the Wind River uplift. Hatched area represents Precambrian outcrops. Numbers along the lines represent station numbers.

tion and lack of magmatism during their origin (e.g. Dickinson and Snyder, 1978; Brewer et al, 1980), can be combined with the crustal structural geometry from seismic reflection studies to better understand the dynamics of plate interaction. The profiles also pose serious new questions for those interested in fault mechanics. What deformation mechanisms must be operating in the middle and lower crust so as to produce the relatively discrete reflections observed along the thrust beneath the Wind River Mountains? The data would suggest that, even in the lower crust in this tectonic setting, failure occurs only along narrow zones of fracture or ductile flow; broad scale ductile flow does not appear to have occurred. Intimately related to this is the question of what actually produces the "fault plan reflection" seen on the COCORP data. Where basement is thrust on sediments, there is little doubt that the contrast in acoustic impedance of the two rock types is responsible. However, where rocks of presumably similar densities and velocities are thrusted together the answer is less clear. Mylonites, water in the fault zone, or juxtaposition of markedly different basement rock types all are plausible alternatives.

ACKNOWLEDGMENTS

The COCORP Wind River study was supported by National Science Foundation grants EAR74-22257, EAR77-14674, and EAR77-13653. We thank various COCORP committees for their continuing advice and interest. Special credit is due to Jon A. Brewer and Scott B. Smithson who did much of the original interpretation of the Wind River lines. The field data were collected by Crew 6834 of Petty-Ray Geophysical, a division of Geosources, Inc. The data were processed primarily by Geosource.

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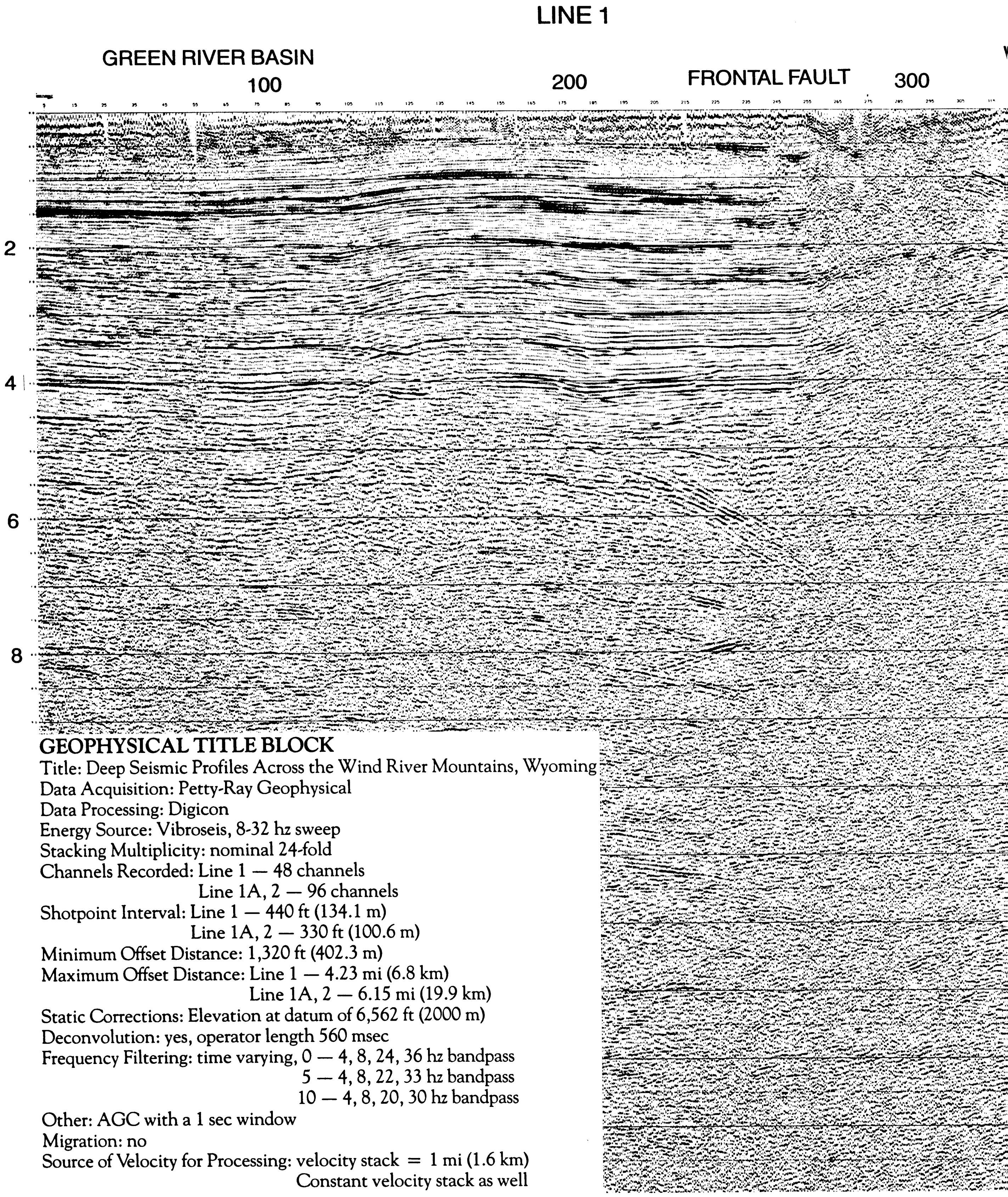
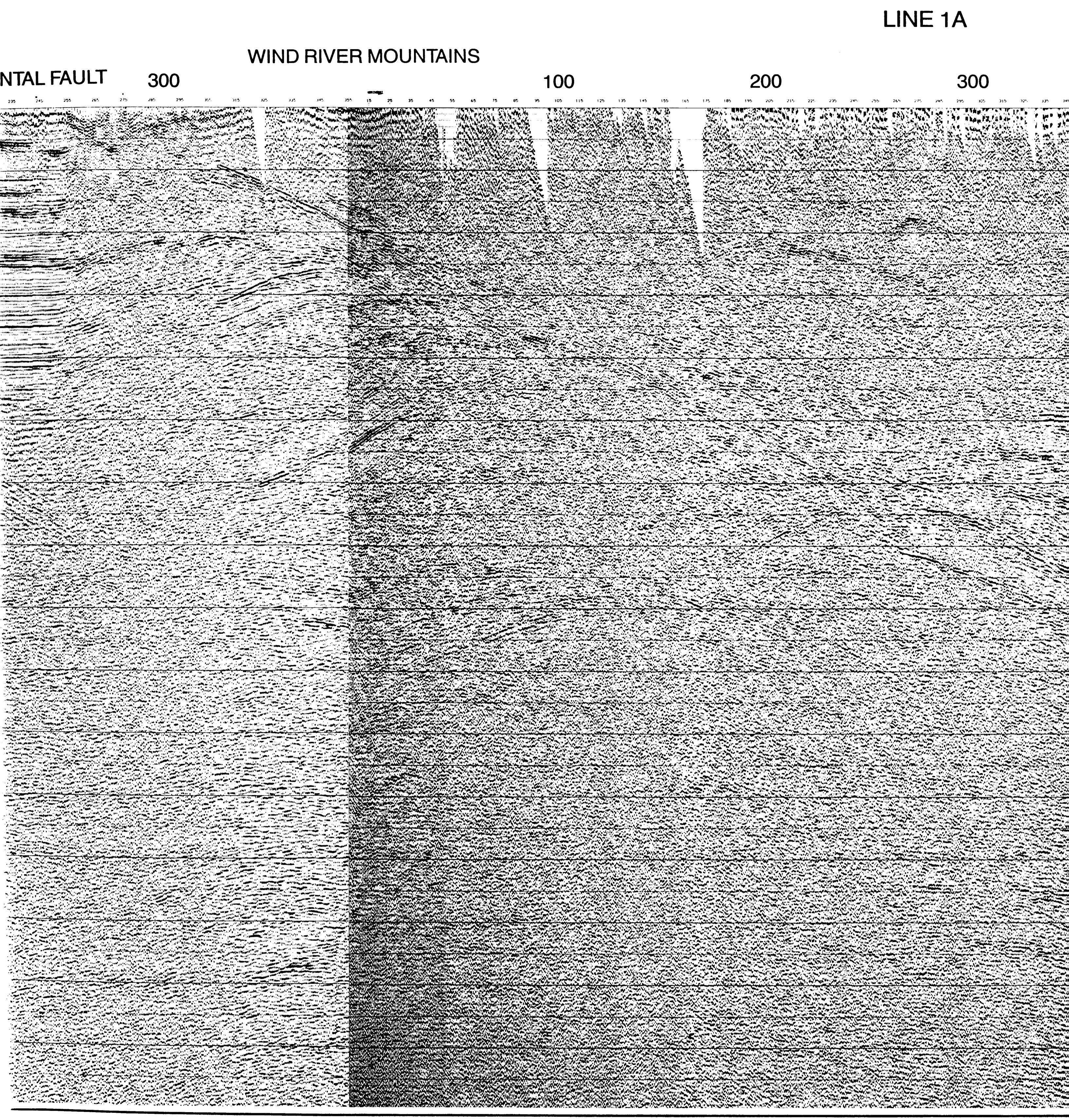


GEOPHYSICAL TITLE BLOCK

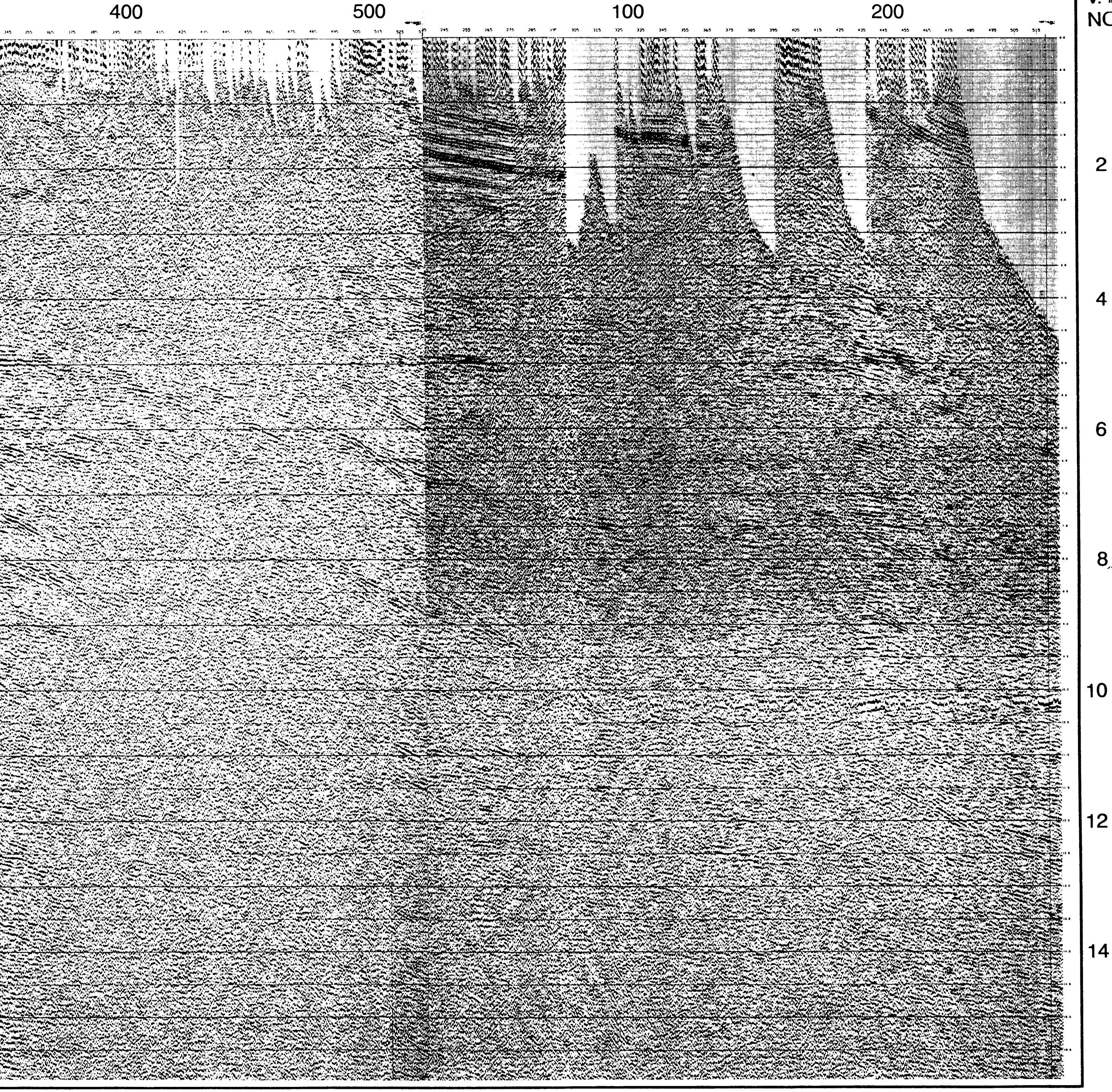
Title: Deep Seismic Profiles Across the Wind River Mountains, Wyoming
Data Acquisition: Petty-Ray Geophysical
Data Processing: Digicon
Energy Source: Vibroseis, 8-32 hz sweep
Stacking Multiplicity: nominal 24-fold
Channels Recorded: Line 1 — 48 channels
Line 1A, 2 — 96 channels
Shotpoint Interval: Line 1 — 440 ft (134.1 m)
Line 1A, 2 — 330 ft (100.6 m)
Minimum Offset Distance: 1,320 ft (402.3 m)
Maximum Offset Distance: Line 1 — 4.23 mi (6.8 km)
Line 1A, 2 — 6.15 mi (19.9 km)
Static Corrections: Elevation at datum of 6,562 ft (2000 m)
Deconvolution: yes, operator length 560 msec
Frequency Filtering: time varying, 0 — 4, 8, 24, 36 hz bandpass
5 — 4, 8, 22, 33 hz bandpass
10 — 4, 8, 20, 30 hz bandpass
Other: AGC with a 1 sec window
Migration: no
Source of Velocity for Processing: velocity stack = 1 mi (1.6 km)
Constant velocity stack as well



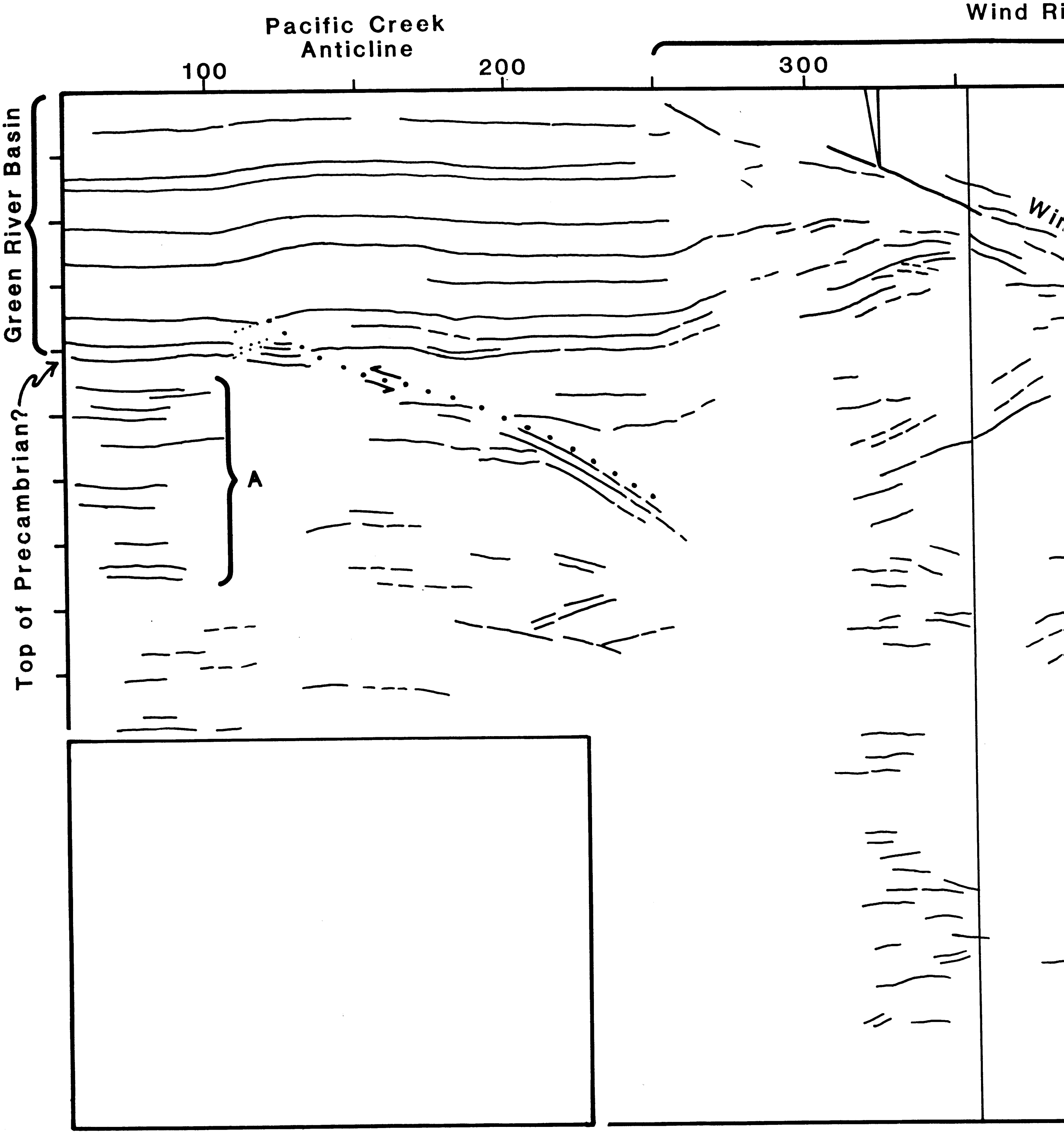
LINE 1A
WIND RIVER MOUNTAINS
NTAL FAULT
300
100
200
300

LINE 2

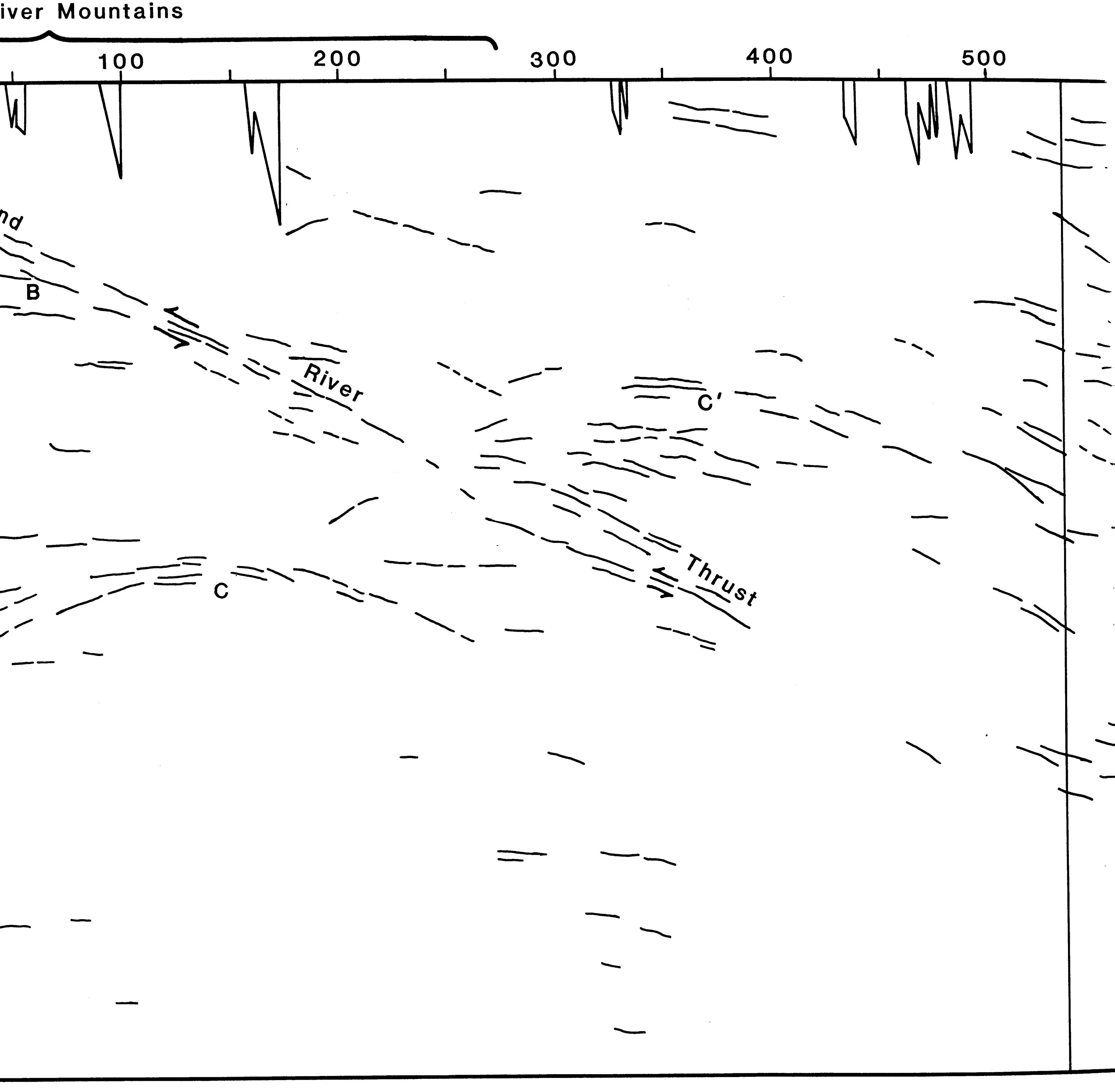
WIND RIVER BASIN



LINE 1

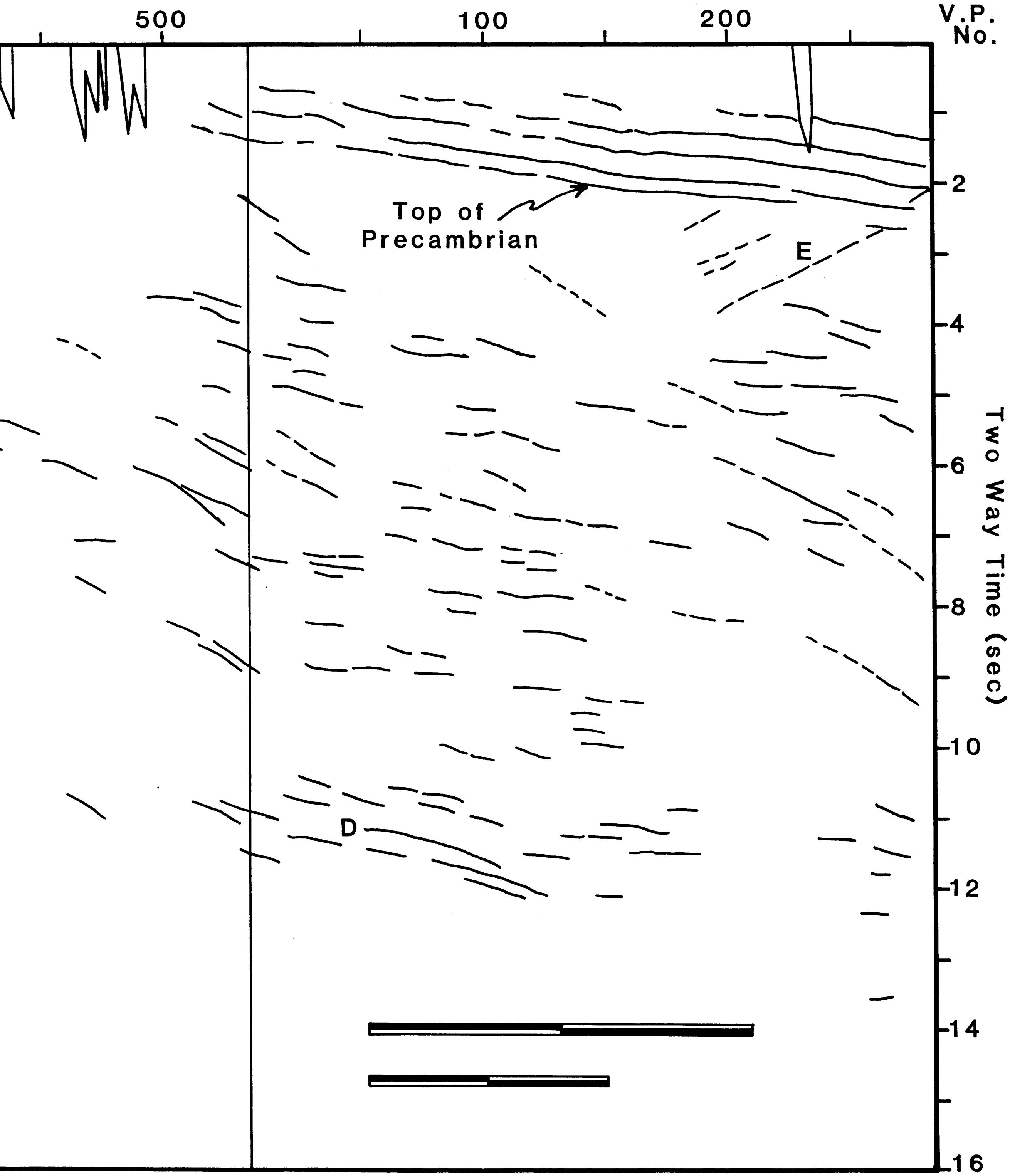

Pacific Creek Anticline
Wind Ri
100
200
300
Green River Basin
Top of Precambrian?
A
Win

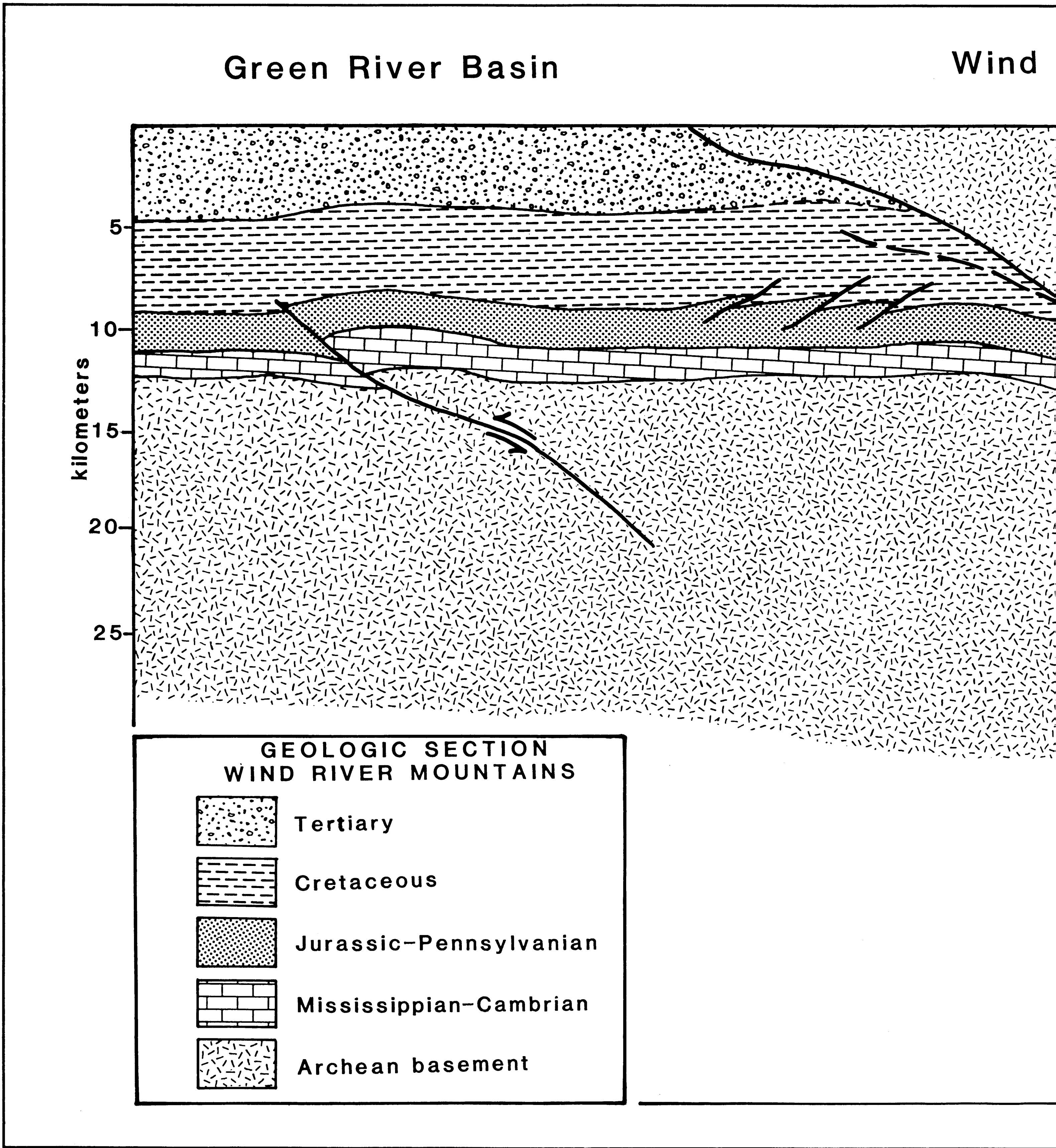
LINE 1A



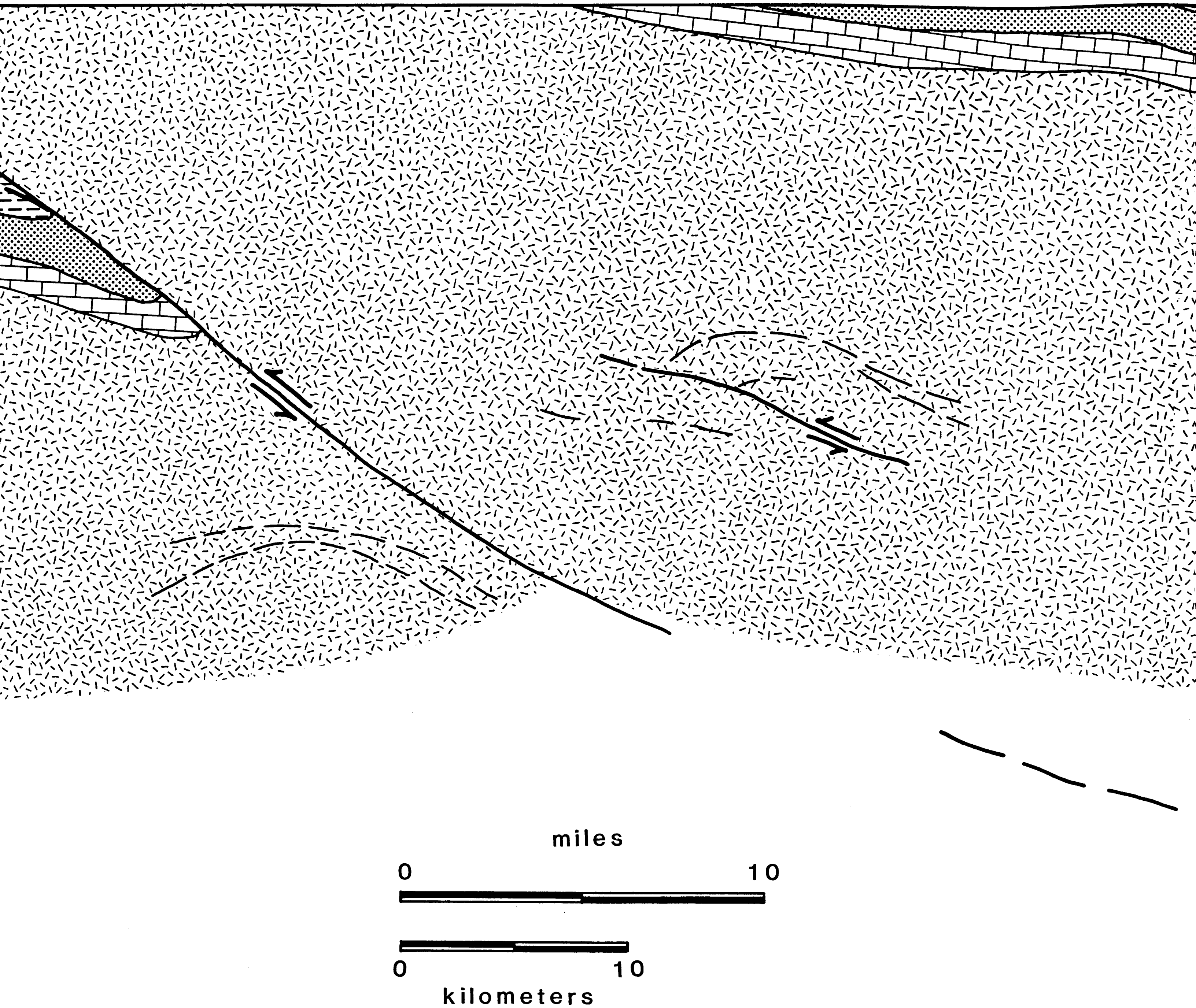
LINE 2

Wind River Basin




Green River Basin
Wind
5
10
15
20
25
kilometers
GEOLOGIC SECTION
WIND RIVER MOUNTAINS
Tertiary
Cretaceous
Jurassic-Pennsylvanian
Mississippian-Cambrian
Archean basement

d River Mountains



Wind River Basin