

INTRODUCTION AND LOCATION

The Consortium for Continental Reflection Profiling (COCORP) collected more than 350 km of 48-fold deep seismic reflection profiles from central and western Utah during Spring and Fall of 1982. The profiles constitute a crustal scale transect across the Cordilleran Hinge Zone in Utah, a zone that has been active during Late Precambrian rifting, Mesozoic and Early Cenozoic thrusting, and Middle and Late Cenozoic rifting. The survey consists of three main east-west lines, Utah lines 1, 3, and 4, and three shorter cross-lines (lines 2, 5, and 6) (Fig. 1). Line 1 is shown here (Fig. 2): all of the lines are described in more detail in Allmendinger and others (1983), Von Tish and others (in press), Sharp and others (in prep.), and Farmer and others (in prep.). Line 1 illustrates the geometry and interaction of Cenozoic low-angle normal faults and Mesozoic thrust faults with the autochthonous Late Precambrian-Paleozoic hingeline (Figs. 3, 4).

COCORP Utah Line 1 is located in Millard County, Utah, between the Utah-Nevada border on the west and Interstate 15 on the east (Fig. 1). The west end of the line is just east of the Northern Snake Range, a Cenozoic metamorphic core complex and the site of the Snake Range decollement (Misch, 1960; Miller et al., 1983). From west to east, the line crosses: 1) the Confusion Range Synclinorium, a structure mostly Mesozoic in age which exposes a 10 km (6 mi) thick section of Cambrian to Triassic strata (Hose, 1977); 2) the House Range, a gently east-dipping homocline of Cambrian rocks, intruded by a Jurassic stock and bounded on the west side by a steep Cenozoic normal fault (Hintze, 1974); and 3) the Sevier Desert Basin, which, near Delta, Utah, is more than 4,500 m (14,760 ft) deep and is filled by Oligocene and younger sedimentary and volcanic rocks (McDonald, 1976; Lindsey et al., 1981; Von Tish et al., in press). The east end of the line is at Scipio Pass between the Canyon and Pavant Ranges, which expose Cretaceous thrust plates. The line is oriented east-west, approximately perpendicular to structural and stratigraphic strike, as confirmed by surface geologic data and by cross lines 2, 5, and 6 (Fig. 1). The line is about 170 km (105 mi) long and is comprised of 1,650 vibration points (VP's).

GEOLOGY OF THE CORDILLERAN HINGELINE REGION IN CENTRAL UTAH

The region of the Cordilleran Hingeline (referred to here as the "Hinge Zone"), commonly called the "Wasatch Line" in Utah, is a long-lived, diffuse boundary that separates the orogenically modified edge of the North American craton from the more stable, less deformed interior of the continent. The hingeline is defined as the axis west of which Late Precambrian and Paleozoic miogeoclinal strata thicken markedly (Kav, 1951; Stokes, 1976). This axis was formed during Late Precambrian rifting of the western margin of North America and subsequent development of a passive continental margin during the early Paleozoic (Stewart, 1972). The age of the initial rifting event has long been uncertain because the syngenetic and early post-rift deposits are poorly dated. However, recent application of back-stripping techniques (Armin and Mayer, 1983; Bond and Komniz, 1984) suggest that rifting occurred in the latest Proterozoic, less than 650 m.y. ago. The passive margin remained virtually uninterrupted, until the end of the Devonian and the onset of the Antler Orogeny (Dickinson, 1977; Speed, 1982). Thus, the passive margin of western

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North America existed for about 300 m.y., almost twice as long as its modern counterpart on the east coast of North America. The present width of this ancient passive margin, measured from the hingeline on the east to the westernmost miogeoclinal deposits and the $Sr^{87}/Sr^{86} = .706$ isopleth that define the westernmost North American basement (Speed, 1982) is about 400 km (250 mi). Due to superposed younger deformations, the original width is unknown.

Although middle and late Paleozoic orogenies (representing the accretion of allochthonous terranes) occurred in central and western Nevada, the Hinge Zone in central Utah remained undeformed until the Sevier Orogeny in the Cretaceous and Early Tertiary (Armstrong, 1968). At least three major thrust faults are recognized in central Utah: 1) the structurally highest Canyon Range thrust (Fig. 1) that carried a thick sequence of Upper Proterozoic and Paleozoic strata in its hanging wall; 2) the middle Pavant Range thrust (Fig. 1) that, where exposed, contains Lower Cambrian and younger clastic strata in its upper plate; and 3) the lowest thrust (informally referred to here as the "sub-Pavant thrust") which is nowhere exposed at the surface but is known from industry drilling and seismic reflection data (Ritzma, 1972; Standlee, 1982; Sharp et al., in prep.; D. Sprinkel, pers. comm., 1982). The thrusts are not well dated, but probably range in age from the Cretaceous (Albion) to the Early Tertiary (Spieker, 1946; Lawton, 1983; Villien and Kligfield, in press). The Mesozoic-Early Tertiary thrust belt extends at least as far east as the west side of the Wasatch Plateau and may extend farther east as a blind thrust fault in the Jurassic section (Standlee, 1982; Villien and Kligfield, in press; Farmer et al., in prep.). No major thrust faults structurally higher than the Canyon Range thrust have been recognized between the Canyon Range and the Utah-Nevada border, although some small thrust faults occur in the Confusion Range (Fig. 1) (Armstrong, 1968; Sharp et al., in prep.).

Most recently, the Hinge Zone has been deformed by extensional tectonism that ultimately produced the Basin and Range Province. Zoback and others (1981) proposed that this extension took place in two discrete pulses: an earlier phase, beginning in the Oligocene, of low-angle normal faulting and accompanying calc-alkaline volcanism that occurred during the waning phases of subduction beneath the continent, and a later Miocene and younger phase of higher angle normal faulting that resulted in the formation of the present basin-range morphology of the province. In west-central Utah, Von Tish and others (in press) recognized deformational hiatuses but only one distinct style and resolvable rate of extension. This extension, dominated by low-angle normal faulting, probably began in the Late Oligocene and is at least as young as 1 m.y.b.p. Low-angle normal faults in eastern Nevada and west-central Utah have been described by Armstrong (1972), McDonald (1976), Allmendinger and others (1983), and Miller and others (1983).

HISTORY OF EXPLORATION IN THE REGION

Exploration in western and central Utah has provided crucial information on the subsurface structure of the region. Twelve exploratory holes have been drilled within 40 km (25 mi) of COCORP Utah Line 1; eight key boreholes are shown in Figure 1 and summarized in Table 1. Numerous other holes have been

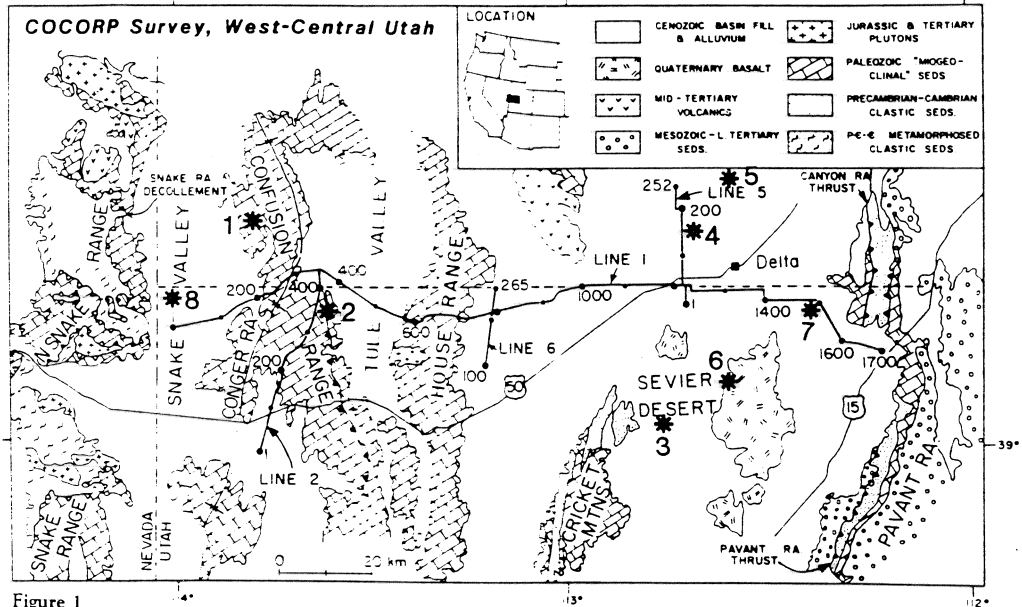


Figure 1

Figure 1: Location map and generalized geology of the COCORP survey in west-central Utah. Line 1 is the only COCORP profile shown here. Lines 3 and 4 are located east of the area of this map. Heavy asterisks show the locations of the petroleum exploration boreholes in the region. Numbers correspond to those shown in Table 1. Thin dashed east-west oriented line indicates line of section for depth section in Figure 4. Map modified from Allmendinger and others (1983).

drilled farther to the north, south, and especially to the east. In the region mostly east of Line 1, the exploration targets have mainly been sub-thrust plays in Mesozoic and upper Paleozoic strata. Particular attention has been paid to the highly deformed Jurassic evaporite sequence of the Arapien Formation because of its potential for both structural and stratigraphic traps, and because partly equivalent-aged rocks farther east (the Carmel Formation) and north (the Twin Creek Limestone) have had shows and may be source beds (Moulton, 1975; Standlee, 1982; Sprinkel, 1982). In the central part of the region, stratigraphic tests have been made in the Cenozoic Sevier Desert Basin, and sub-thrust plays have also been drilled in Paleozoic and Precambrian strata beneath the Cenozoic basin (McDonald, 1976; Mitchell, 1979; Lindsey et al., 1981). One of the earliest wells in the region (drilled in 1957) was the Gulf No. 1 Gronning well, located about 10 km (6 mi) north of Line 1. That well provides some of the best information on the age and lithologies of Tertiary basinal strata of the Sevier Desert. In the western part of the region, west of the Tule Valley, targets have been drilled in fold and thrust related structures in the middle and upper Paleozoic strata of the Confusion Range Synclinorium, with particular interest in Mississippian and Pennsylvanian black shale and argillite of the Manning Canyon and Chainman formations as source rock. Recent interest in the region has focused on a large antiformal structure beneath the House Range that was defined by COCORP Utah Line 1 (Figs. 1, 2, 3).

INTERPRETATION OF COCORP UTAH LINE 1

There are two considerations to bear in mind with respect to COCORP data shown here, as compared to most industry data displayed in other parts of this volume. First, COCORP surveys are used to study the entire crust. Though this approach results in a small loss in resolution in the shallow section, it allows one to trace shallow structures to deep levels in the crust, and to see how those deep structures influence and modify shallow crustal structures and basin geometries. These deep structures have no hydrocarbon potential, but they played an important role in the genesis of shallow thrust and normal faults of interest to explorationists that are largely covered by Tertiary and Quaternary basin fill. Second, most COCORP lines are regional transects, rather than detailed three-dimensional studies of individual structures. Although, some control on cross-dip is lost, the COCORP lines provide a reconnaissance look at very large, regional structures, across many tens of miles perpendicular to strike.

The most striking aspect of Utah Line 1 is the cross-strike lateral continuity of many individual reflection events (Fig. 2). The Sevier Desert Detachment and the House Range Detachment (Fig. 3) together provide overlapping lateral continuity across more than 120 km (75 mi). This continuity continues beneath both basins and ranges in west-central Utah. Seismic modeling by C. Peddy (Peddy and Brown, in prep.) shows that neither one of these events has been offset vertically by more than 300-500 m (980-1650 ft), an amount far smaller than the vertical structural relief represented by the thickness of the Cenozoic sedimentary basins. Thus, most of the Cenozoic extension in the region must have been accommodated by down-to-the-west, normal displacement on both the Sevier Desert and the House Range detachments (Allmendinger et al., 1983). The Sevier Desert Detachment has been penetrated by the Argonaut Energy No. 1 Federal, Arco Pavant Buttes No. 1, and Placid Henley No. 1 wells. The Snake Range "decollement," on the westernmost end of Line 1 is a low-angle normal fault with a sense of displacement (down-to-the-east) opposite to other structures in the region. This fault was penetrated by the Amerada Hess No. 1-28 Federal well (Fig. 3).

Although Late Cenozoic deposits cover more than 70% of the surface along the line, the Mesozoic-Early Cenozoic structure of the region can be inferred from the seismic data, from drilling data near the east and west ends of the line, and from the nature of the unconformity separating

Oligocene rocks from underlying Paleozoic and Precambrian strata. Oligocene rocks blanket rocks deformed only by the earlier, east-directed thrust-faulting episode. Therefore, beneath the horizontally restored unconformity, originally east-dipping strata may indicate the position of a hanging-wall ramp, west-dipping strata indicate a footwall ramp, and horizontal strata indicate a thrust flat. If this interpretation is correct, major Mesozoic thrust ramps were present beneath and east of the Sevier Desert Basin and between the Confusion Range and the House Range, and a long thrust flat was located beneath the House Range (Sharp et al., in prep.). At the east end of the line, thrust faults are exposed in the Canvon and Pavant Ranges (Fig. 1), and have been drilled in the Placid Henley No. 1 and in the Cominco No. 2 Beaver River. On the west end of the line, a small thrust was drilled on the west side of the Confusion Range Synclinorium by the Tiger Oil No. 1 USA-Bishop Springs well, and an asymmetric anticline beneath a thrust exposed on the east side of the same synclinorium was drilled by the Cities Service No 1 State-AB well.

Seismic, borehole, and field data were used to construct the balanced cross section shown in Figure 4. This cross section is just one of several geometrically and geologically reasonable alternative interpretations (see Sharp et al., in prep., for a more detailed discussion of the alternatives). The cross section shows that the Sevier Desert Detachment reactivates the Pavant Range thrust, however, equally plausible cross sections have been constructed interpreting the Sevier Desert Detachment as a new Cenozoic normal fault. The section shown (Fig. 4) has about 45 km (28 mi) of extension and 120 km (75 mi) of shortening when restored (Sharp et al., in prep.)

The cross section also shows the autochthonous position of the Precambrian-Paleozoic hingeline just east of the axis of the Cenozoic Sevier Desert Basin (Fig. 4). West of the hingeline, both Mesozoic thrust faults and Cenozoic low-angle normal faults are interpreted to cut into Precambrian crystalline basement (see the splays on Figures 3, 4; these are interpreted as a Mesozoic basement duplex responsible for the 10 km (6 mi) of pre-Oligocene structural relief between the House and Confusion Ranges). East of the hingeline, there is little evidence that thrust structures involve Precambrian crystalline basement, based on seismic and borehole data. Thus, the thrust faults, and perhaps the subsequent low-angle normal faults, may have been controlled by the structures and basin geometries produced during the Late Precambrian rifting of the western margin of North America.

COCORP DATA ACQUISITION AND PROCESSING

Because the overall objective of the COCORP project is to obtain an acoustic image of the entire crust, the field parameters used in a COCORP survey are somewhat different than those used in a standard industry survey. As shown in Table 2, COCORP uses a longer spread length (9.6 km, 6 mi), longer station spacing (100 m, 330 ft), and longer near offset (4 stations or 400 m, 1,320 ft). Vibrating and recording times are adjusted to produce longer time sections, generally between 15 and 20 sec. two-way time. Also because of the limited frequency content of signals returning from the deep continental basement, COCORP uses an 8-32 Hz upsweep; higher frequencies that would enhance shallow reflections are not used. COCORP data are processed (Table 2) in a manner generally similar to that used by industry, although the longer record lengths require selective application of advanced processing techniques and techniques applied to shot point, rather than CDP gathers (e.g. F-K filtering, migration before stack, etc.). On the stacks displayed here (Fig. 2), F-K filtering was applied only to the first 100 VP's.

ACKNOWLEDGEMENTS

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REFERENCES

- Allmendinger, R.W., Sharp, J.W., Von Tish, D., Serpa, L., Brown, L., Kaufman, S., Oliver, J., and Smith, R.B., 1983. Cenozoic and Mesozoic structure of the eastern Basin and Range Province, Utah, from COCORP seismic reflection data: *Geology*, v. 11, p. 532-536.
- Armin, R., and Maver, L., 1983. Subsidence analysis of the Cordilleran miogeocline: implications for timing of late Proterozoic rifting and amount of extension: *Geology*, v. 11, p. 702-705.
- Armstrong, R.L., 1968. Sevier orogenic belt in Nevada and Utah: *Geological Society America Bull.*, v. 79, p. 429-458.
- Armstrong, R.L., 1972. Low-angle (denudation) faults, hinterland of the Sevier orogenic belt, eastern Nevada and western Utah: *Geological Society America Bull.*, v. 83, p. 1729-1754.
- Bond, G., and Komniz, M., 1984. Construction of tectonic subsidence curves for the early Paleozoic miogeocline, southern Canadian Rocky Mountains: Implications for subsidence mechanisms, age of breakup, and crustal thinning: *Geological Society of America Bull.*, v. 95, p. 155-173.
- Dickinson, W.R., 1977. Paleozoic plate tectonics and the evolution of the Cordilleran continental margin: Pacific Coast Paleogeography Symposium 1, Paleozoic Paleogeography of the Western U.S., Society of Economic Paleontologists and Mineralogists, p. 137-157.
- Farmer, H., et al., in prep., COCORP deep seismic reflection profile across the transition zone between Basin and Range and Colorado Plateau, central Utah.
- Hintze, L.F., 1974. Preliminary geologic map of the Notch Peak quadrangle, Millard County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-636, scale 1:48,000.
- Hose, R.K., 1977. Structural geology of the Confusion Range, west-central Utah: U.S. Geological Survey Prof. Paper 971, 9 p.
- Kay, M., 1951. North American geosynclines: *Geological Society of America Memoir* 48, 143 p.
- Lawton, T., 1982. Lithofacies correlations within the Upper Cretaceous Indianola Group, central Utah: Utah Geological Assoc. Publication 10, p. 199-213.
- Lindsev, D.A., Glanzman, R.K., Naeser, C.W., and Nichols, D.J., 1981. Upper Oligocene evaporites in basin fill of Sevier Desert region, western Utah: *American Association of Petroleum Geologists Bull.*, v. 62, p. 251-260.
- McDonald, R.E., 1976. Tertiary tectonics and sedimentary rocks along the transition: Basin and Range Province to plateau and thrust belt province. Utah: in Hill, J.G., *Geology of the Cordilleran Hingeline*, Rocky Mountain Assoc. Geologists, p. 281-317.
- Miller, E.L., Gans, P.B., and Garing, J., 1983. The Snake Range decollement: an exhumed mid-Tertiary Ductile-Brittle transition: *Tectonics*, v. 2, p. 239-263.
- Misch, P., 1960. Regional structural reconnaissance in central-northeastern Nevada and some adjacent areas: Observations and interpretations: in Intermountain Association of Petroleum Geologists, 11th Annual Field Conference, Guidebook, p. 17-42.
- Mitchell, G.C., 1979. Stratigraphy and regional implications of the Argonaut Energy No. 1 Federal, Millard County, Utah: in Rocky Mountain Assoc. Geologists Symposium, p. 503-514.
- Moulton, F., 1975. Lower Mesozoic and upper Paleozoic petroleum potential of the Hingeline area, central Utah: in Rocky Mountain Assoc. Geologists 1975 Symposium, p. 87-97.

- Ritzma, H., 1972, Six Utah "Hingeline" wells: Utah Geological Assoc., Publication 2, p. 75-80.
- Sharp, J., Allmendinger, R.W., and Von Tish, D., in prep., Palinspastically restored cross sections of west-central Utah constrained by COCORP seismic reflection data.
- Speed, R., 1982, Evolution of the sialic margin in the central western United States, in Watkins, J.S. and Drake, C.L., (eds.), Studies in continental margin geology: American Association of Petroleum Geologists Memoir 34, p. 457-468.
- Spieker, E.M., 1946, Late Mesozoic and Early Cenozoic history of central Utah: U.S. Geological Survey Prof. Pap. 205-D, p. 117-160.
- Sprinkel, D., 1982, Twin Creek Limestone-Arapien Shale relations in central Utah: Utah Geological Assoc. Publication 10, p. 169-179.
- Standlee, L., 1982, Structure and stratigraphy of Jurassic rocks in central Utah: Their influence on tectonic development of the Cordilleran foreland thrust belt: Rocky Mountain Assoc. of Geologists 1982 Symposium, p. 357-382.
- Stewart, J.H., 1972, Initial deposits in the Cordilleran geosyncline: evidence of a Late Precambrian (< 850 m.y.) continental separation: Geological Society of America Bull., v. 83, p. 1345-1360.
- Stokes, W., 1976, What is the Wasatch Line?: Rocky Mountain Assoc. Geologists, 1976 Symposium, p. 11-25.
- Villien, A., and Kligfield, R., in press, Structural overview of thrusting and sedimentation in central Utah, in Peterson, J.A., and Smith, D.L., (eds.), Paleotectonics and sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir.
- Von Tish, D., Allmendinger, R.W., and Sharp, J., in press, History of Cenozoic extension in the central Sevier Desert, west-central Utah, from COCORP seismic reflection data: American Association of Petroleum Geologists Bull.
- Zoback, M.L., Anderson, R.E., and Thompson, G.A., 1981. Cainozoic evolution of the state of stress and style of tectonism of the Basin and Range province of the western United States: Philosophical Transactions of the Royal Astronomical Society, v. A300, p. 407-434.

TABLE 1: WELLS NEAR COCORP UTAH LINE 1

No.	Well Name	Location	TD (ft)	Remarks
1	Tiger Oil No. 1 USA-Bishop Springs	T16S, R17W, sec 8	16,058	Thrust — Silurian/Devonian at 7,450 ft
2	Cities Service No. 1 State AB	T18S, R16W, sec 2	11,822	Thrust — Lower Ordovician/ Upper Ordovician at 5,802
3	Cominco-American No. 2 Beaver River	T20S, R8W, sec 28	13,193	Thrust — Precambrian/Upper Cambrian at 8,364 ft
4	Gulf Gronning No. 1.	T16S, R8W, sec 24	8,064	Drilled only Tertiary sedimentary and volcanic rock
5	Argonaut Energy No. 1 Federal	T15S, R7W, sec 23	11,266	Salt dome in Tertiary section; Sevier Desert detachment at 7,734 ft
6	ARCO Oil & Gas Pavant Butte No. 1	T19S, R7W, sec 35	11,133	Sevier Desert Detachment at 9,800 ft
7	Placid Oil Henley No. 1	T18S, R5W, sec 15	13,106	Thrust — Upper Cambrian/ Upper Ordovician at 7,467 ft
8	Amerada Hess No. 1-28 Federal	T17S, R19W, sec 28	7,785	Snake Range Decollement at 7,350 ft

**TABLE 2: COCORP UTAH LINE 1
DATA ACQUISITION AND PROCESSING**

FIELD RECORDING PARAMETERS

Recorded by:	Petty Ray Crew No. 6834	Recording instrument:	MDS 10
Date:	4/29/82-6/24/82	No. of channels:	96
Energy source:	VIBROSEIS	Sample rate:	8 msec.
Geophones/channel:	24	Sweep length:	32 sec.
Channel spacing:	100.6 m (330 ft)	Field record length:	52 sec.
Source spacing:	100.6 m (330 ft)	Corr. record length:	20 sec.
No. of Vibrators:	5 (4 min.)	Sweep frequencies:	8-32 Hz
		Sweeps/VP:	8

PROCESSING STREAM

1. Demultiplex
2. Vibroseis correlation
3. F-K Filter
4. Datum statics (Datum 1900 m [6234 ft]: Datum velocity 4500 m/sec. [14765 ft/sec.])
5. CDP gather
6. Trace equalization
7. Velocity analysis (velocity spectra, constant velocity stacks)
8. Normal moveout
9. Mute application
10. Stack — Nominal 48-fold
11. Automatic gain control (1 sec. window)

Data processed at Cornell University with a MEGASEIS system (Trademark Seiscom Delta United)

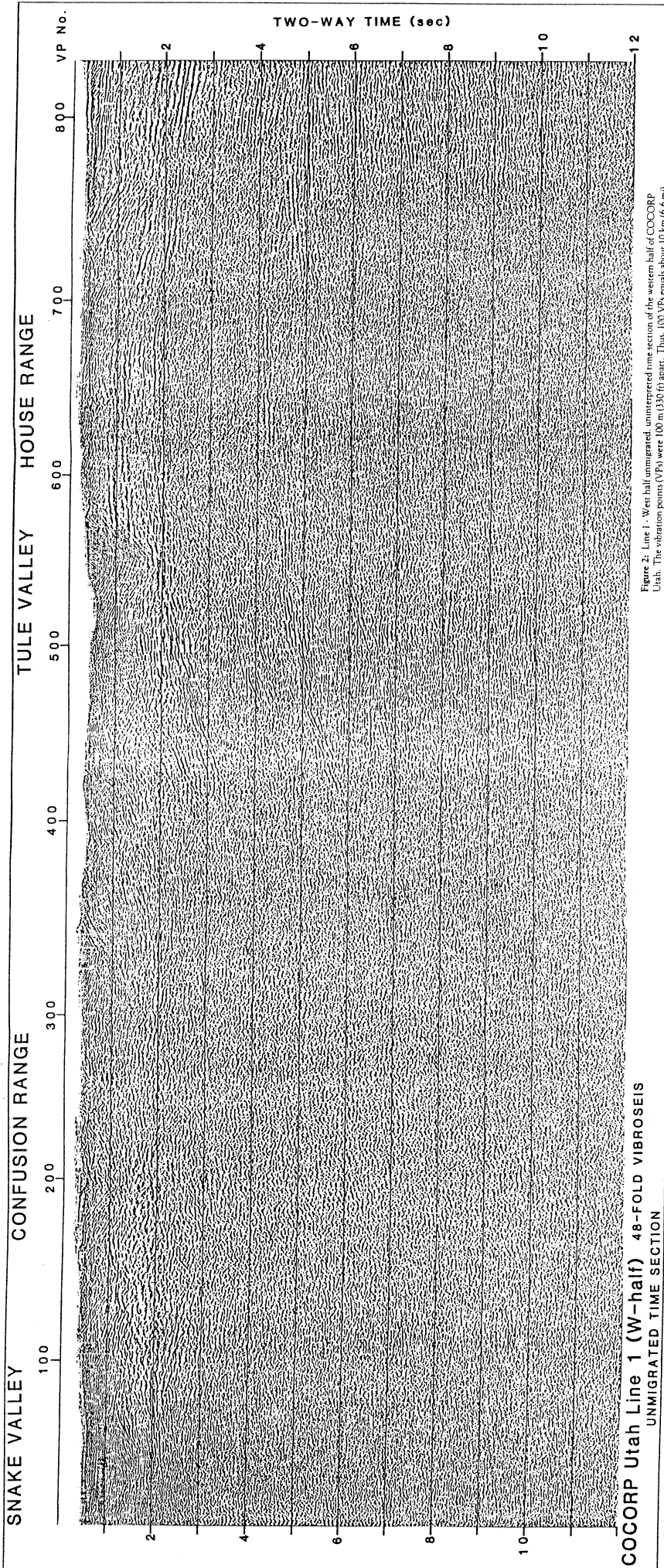


Figure 2: Line 1: West half unmigrated, uninterpreted time section of the western half of COCORP Utah. The vibration points (VPs) were 100 m (330 ft) apart. Thus, 100 VPs equals about 10 km (6.6 mi).

SEVIER DESERT

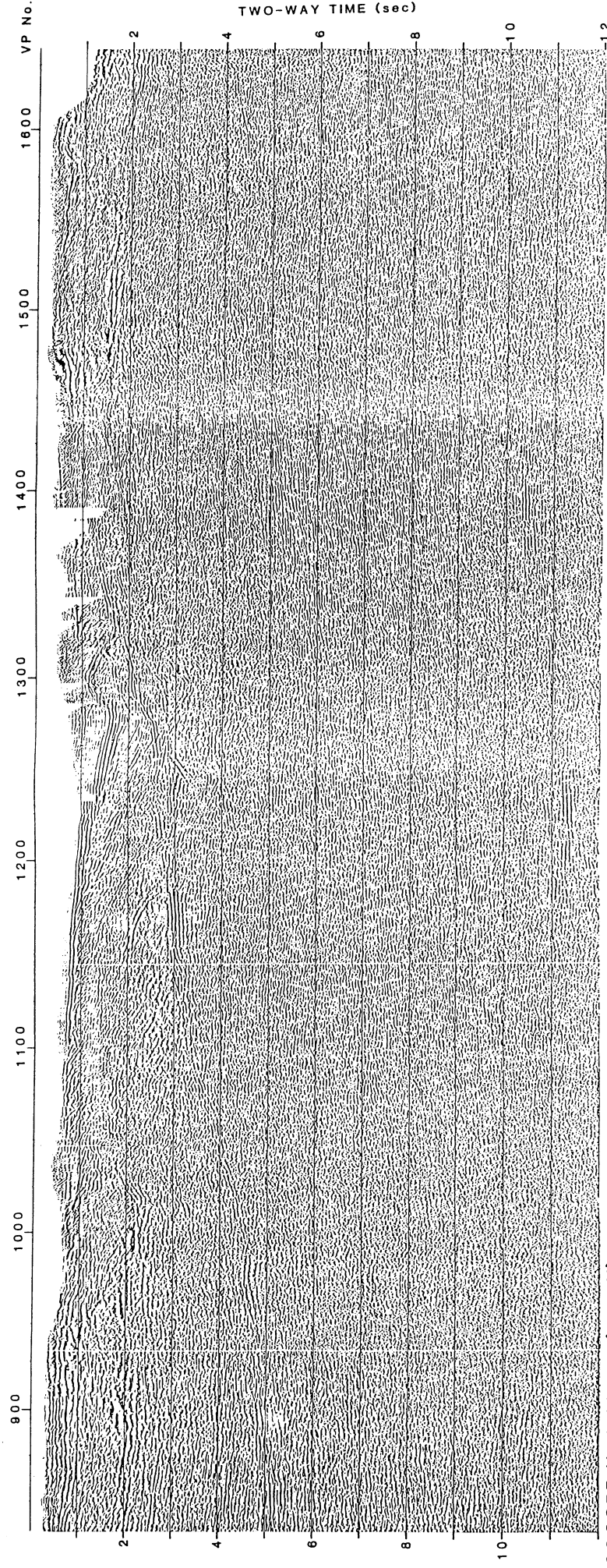
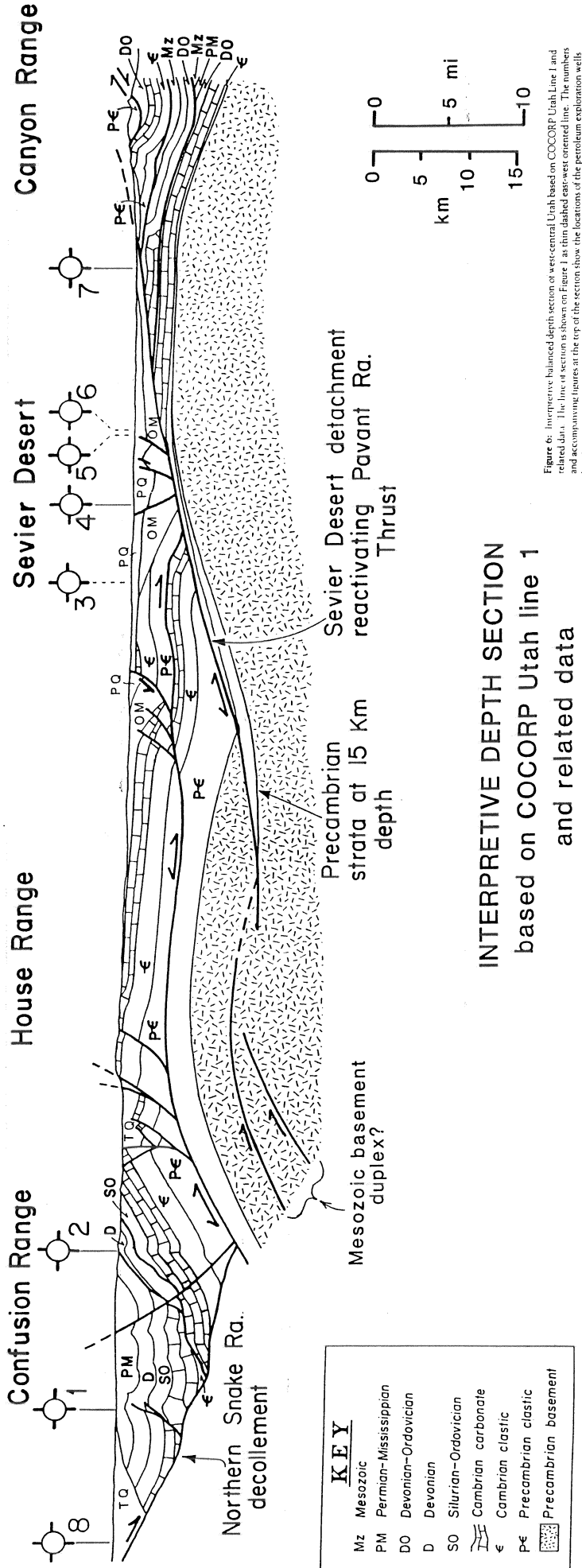


Figure 4: Line 1 - East half, unmigrated, unprocessed time section of the eastern half of COCORP Utah. The vibration points (VPs) were 100 m (330 ft) apart. Thus, 100 VP equals about 10 km (6.2 mi).

COCORP Utah Line 1 (E-half) 48-FOLD VIBROSEIS
UNMIGRATED TIME SECTION

West

East



KEY

Mz	Mesozoic
PM	Permian-Mississippian
DO	Devonian-Ordovician
D	Devonian
SO	Silurian-Ordovician
	Cambrian carbonate
€	Cambrian clastic
P€	Precambrian clastic
	Precambrian basement

**INTERPRETIVE DEPTH SECTION
based on COCORP Utah line 1
and related data**

Figure 6: Interpretive balanced depth section of west-central Utah based on COCORP Utah Line 1 and related data. The line of section is shown on Figure 1 as thin dashed east-west oriented line. The numbers and accompanying figures at the top of the section show the locations of the petroleum exploration wells listed in Table 1. The section is modified after Sharp and others (in prep.).