Tertiary structural development of selected valleys based on seismic data: Basin and Range province, northeastern Nevada

By I. Effimoff and A. R. Pinezich
Shell Oil Company, P.O. Box 831, *Houston, Texas* 77001, *U.S.A.*

[Pullouts 1–6]

Reflexion seismic data in Railroad, Diamond, Mary's River and Goshute Valleys provide information on their structural development that cannot be deduced solely from outcrop and well data.

These valleys contain Tertiary sediments that, in dip section, define an asymmetrical basin bounded along the eastern flank by a major listric normal fault with about 3.0–4.5 km of displacement. The west flank is defined by a gentle east-dipping ramp. Seismically the trace of the listric fault is interpreted to dip westward and sole into the Palaeozoic section exploiting regionally recognized Mesozoic décollement surfaces. The Tertiary depocentre, adjacent to this fault, shifted from west to east with continued slippage through time, the greatest movement occurring in the Miocene and post-Miocene. In the strike direction, the valleys are separated into at least two sub-basins by an east–west structurally high axis. The axis is postulated to be the result of a tear fault associated with movement along the listric normal fault.

Tertiary stratigraphy varies between valleys and between sub-basins in a given valley. All the valleys contain Miocene and younger rocks; however, not all sub-basins contain the pre-Miocene section, suggesting a complex scheme of structural development.

Introduction

The purpose of this study is to demonstrate the similarities and differences in the Tertiary structural development of selected valleys (basins) in the Basin and Range province of northeastern Nevada (figure 1). Railroad, Diamond, Mary's River and Goshute Valleys were chosen as examples for this study because of the availability of abundant geophysical and geological data. Integration of Common Depth Point seismic reflexion profiles with outcrop and well information allowed us to document the structural development of the valleys. Seismic data provide subsurface structural information that cannot be obtained from the latter two sources.

A number of recent publications are devoted to the geological–geophysical framework and the regional tectonic significance of the Basin and Range province of the western United States (Newman & Goode 1979; Smith & Eaton 1978; Armentrout *et al.* 1979), with particularly comprehensive overviews being provided by Eaton (1979) and Stewart (1978). There is general agreement that the present physiographic configuration of the province is the result of Cainozoic extensional deformation and that the precise timing of this deformation may be different for different sections of the province.

Two general models for basin and range structural development have been proposed in the literature and are illustrated in figure 2, which is modified after Stewart (1978). The first model relates to curving, downward flattening normal (listric) faults where the uptilted part of a block forms the range and the downtilted part forms the valley. The second model consists of horsts and grabens that form ranges and valleys, respectively. The structures observed in the

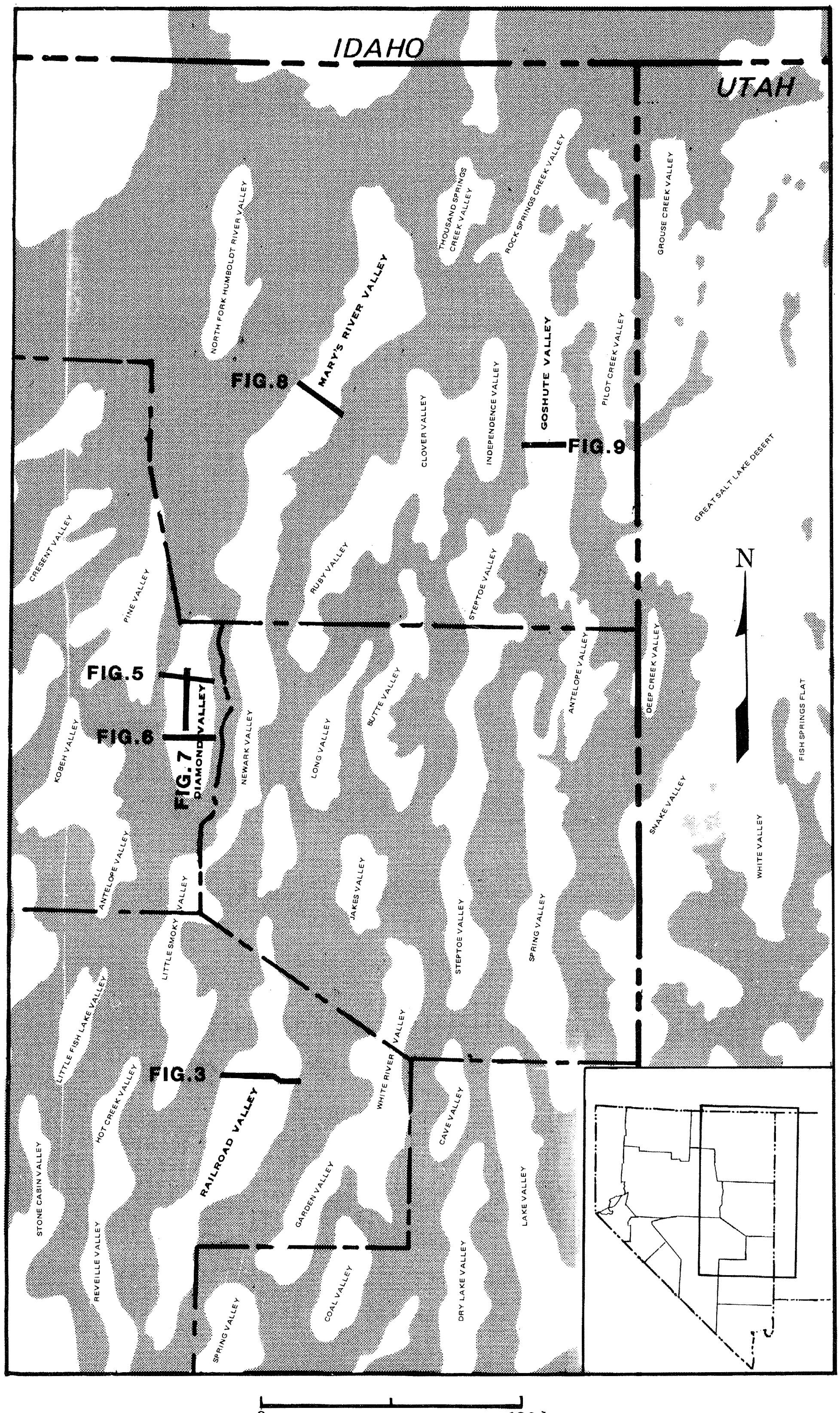
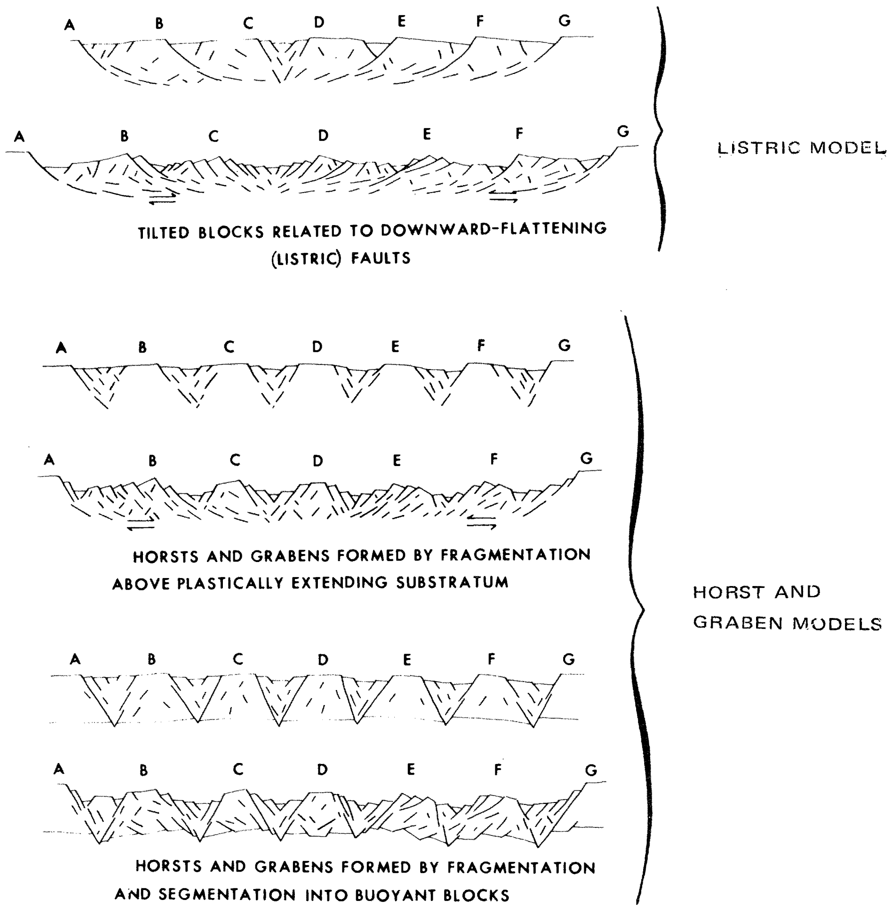


FIGURE 1. Index map for northeastern Nevada illustrating distribution of basins and ranges. Seismic profiles discussed in the text are indicated by figure number.

four valleys chosen for this study favour the first model over the second. However, certain minor elements of the second model can be observed.

Listric faults in other geological provinces have been identified by using seismic reflexion data. Of particular note are papers by Bally *et al.* (1966) and Lowell *et al.* (1975).



Railroad Valley

Railroad Valley is geologically one of the most extensively studied and best understood basins in Nevada owing to the petroleum industry's activity in that valley for over 30 years. Numerous wells have been drilled and many seismic and other geophysical surveys have been conducted in the exploration–production process. Currently it is the only valley in Nevada with oil production; namely, Eagle Springs and Trap Springs fields (Bortz & Murray 1979; Duey 1979).

The interpretation of the seismic dip profile for Railroad Valley presented in figure 3, pullout 1, is the result of integrating all pertinent well and outcrop data in addition to gravity with the seismic data. The seimic profile is representative of all of Railroad Valley in terms of its structural geometry and stratigraphy. The generalized Tertiary stratigraphy of Railroad Valley is shown on figure 4.

The Tertiary sediments in Railroad Valley define an asymmetrical basin bounded on the east by a listric fault along which the Palaeozoic is displaced 4.5 km feet vertically. The listric fault grades downdip into a more prominent west-dipping, low-angle plane, and can be traced only to about the middle of the profile. To the east the décollement surface into which the low-angle listric fault appears to sole continues beneath the Grant Range, which flanks the valley. This surface has not been observed in the outcrop of the Grant Range (Kirkpatrick 1960), but it can be postulated that the seismic reflexion into which the listric fault soles is the Mississippian Chainman shale. The Chainman has been observed in what may be considered a foot wall position of the valley during the development drilling at Eagle Springs field (Bortz & Murray 1979).

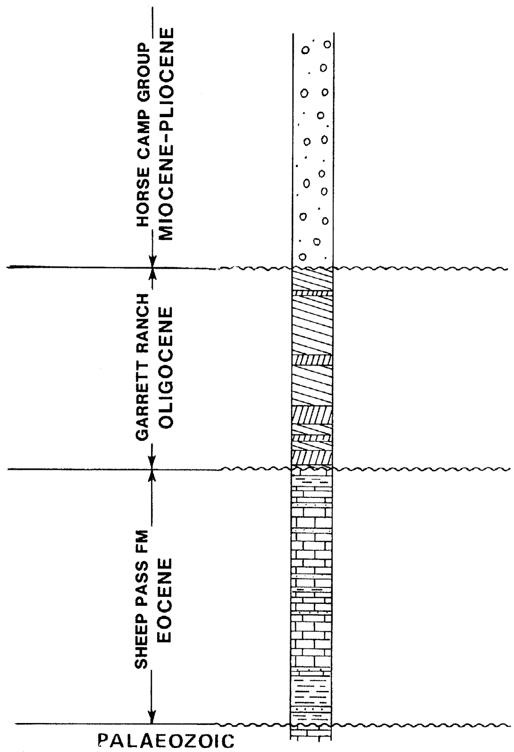


FIGURE 4. Generalized type section for the Tertiary in Railroad Valley. Horse Camp Group: fluvial and lacustrine clastics; Garrett Ranch formation: ignimbrites, volcanoclastics and some rhyolitic–dacitic flows; Sheep Pass formation: lacustrine carbonates and shales with minor clastic components.

The western flank of the Tertiary basin is defined by a gently eastward-dipping ramp and is considered to be the hanging wall of the low-angle, westward-dipping listric fault. In the hanging wall, Palaeozoic units extend approximately over the western two-thirds of the valley and lower Tertiary units extend over the remaining eastern third. The foot wall consists exclusively of Palaeozoic units. The geometric relation of the Tertiary units to the listric fault suggest that the basin may have been initiated by extension in lower Tertiary time since the Lower Tertiary directly overlies the listric fault along the eastern flank of the basin. This observation is supported by detailed stratigraphic studies of the late Cretaceous (?) to early Oligocene Sheep Pass formation which overlies the Palaeozoic across an uncomformity (Bortz & Murray 1979); Fouch 1977, 1979; Winfrey 1960; Newman 1979) and from regional studies of Tertiary lacustrine sediments (MacDonald 1976).

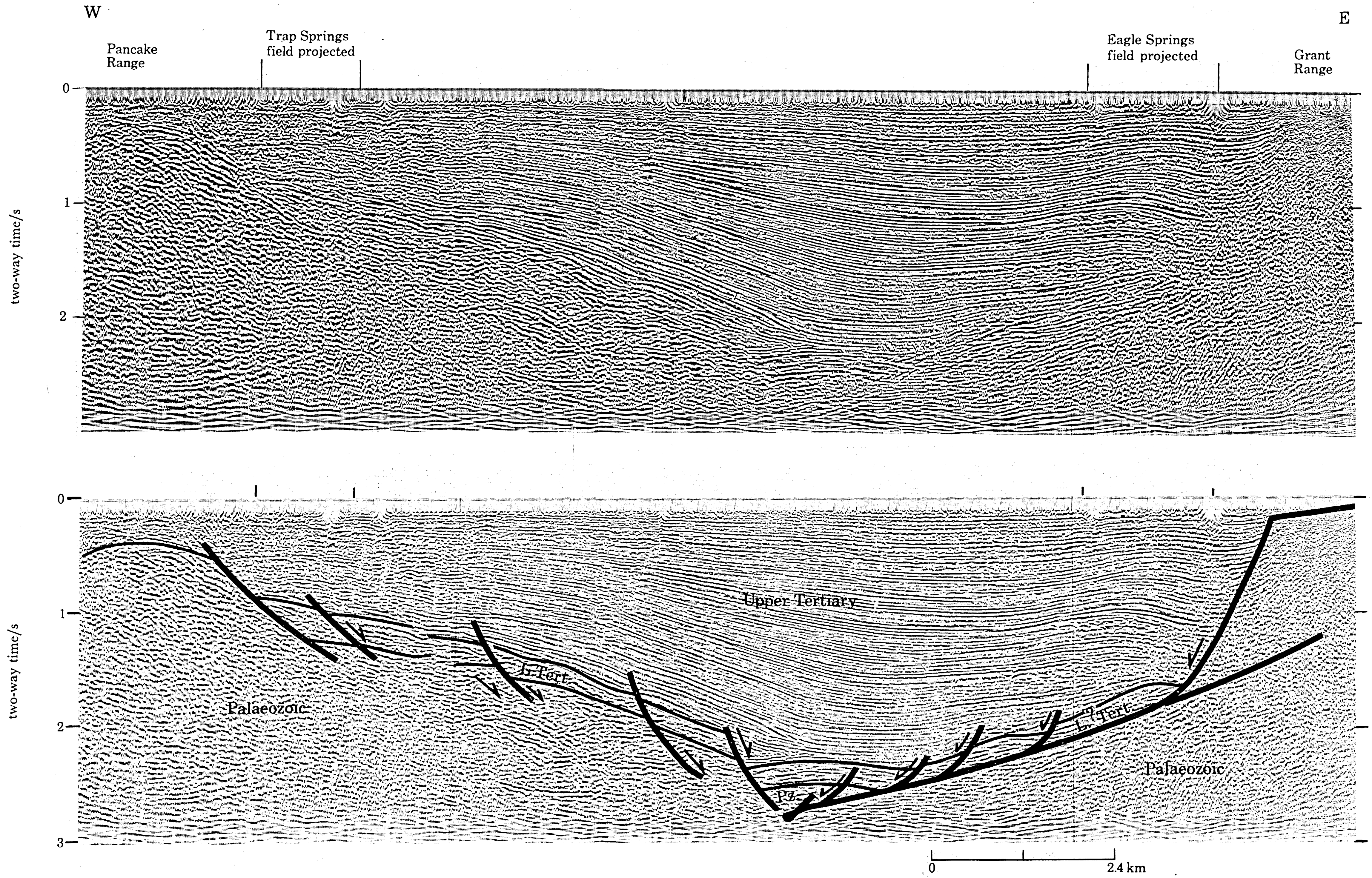


FIGURE 3. Seismic dip profile for Railroad Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 4.5 km.

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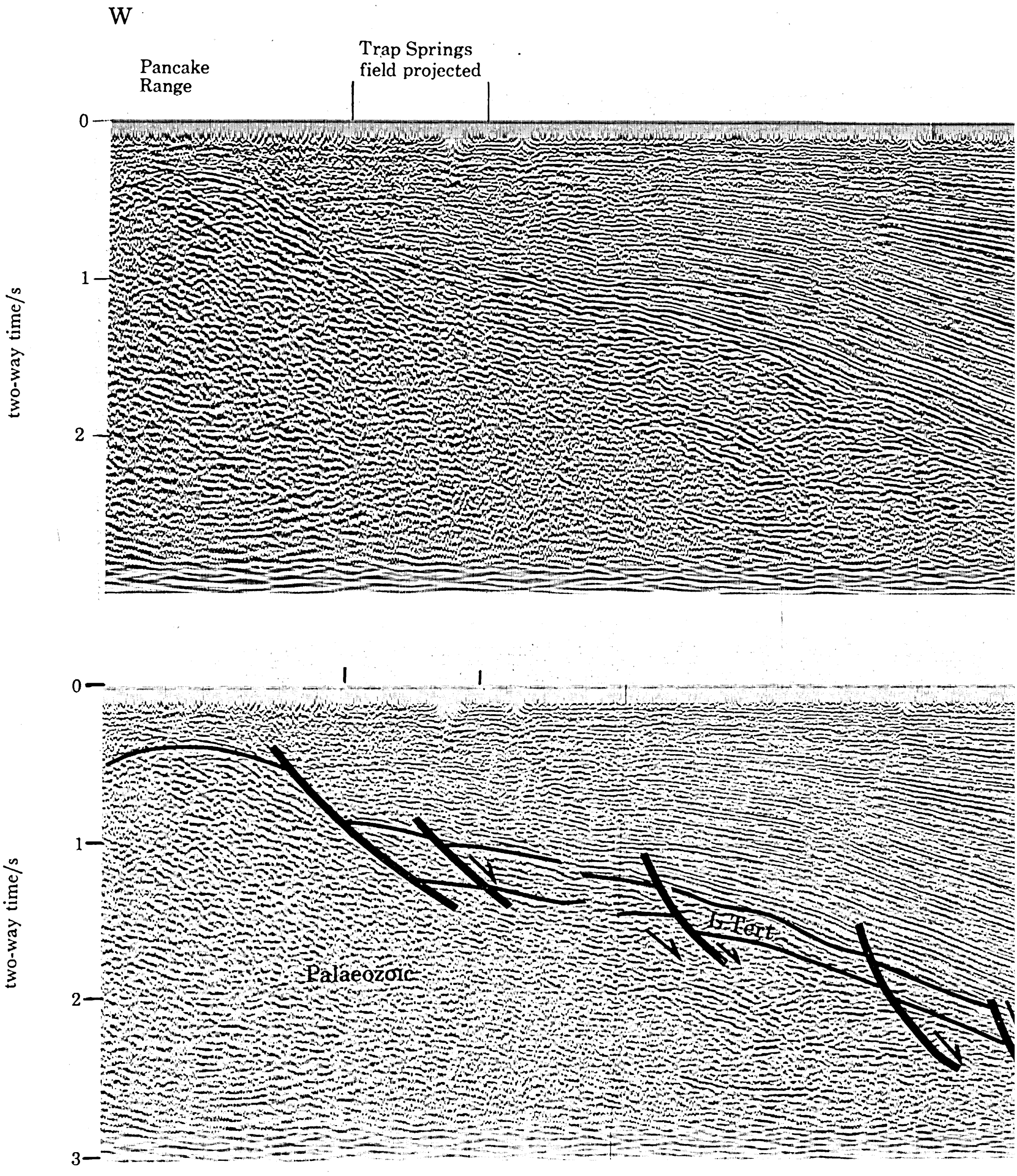

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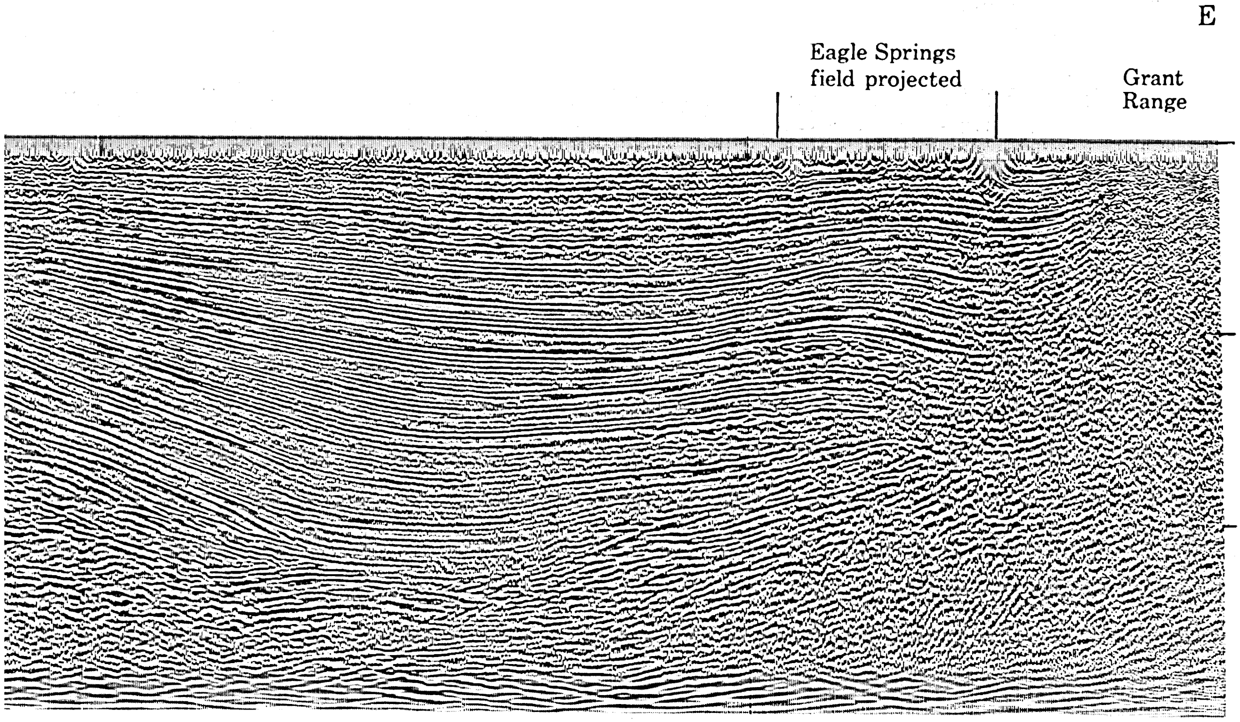

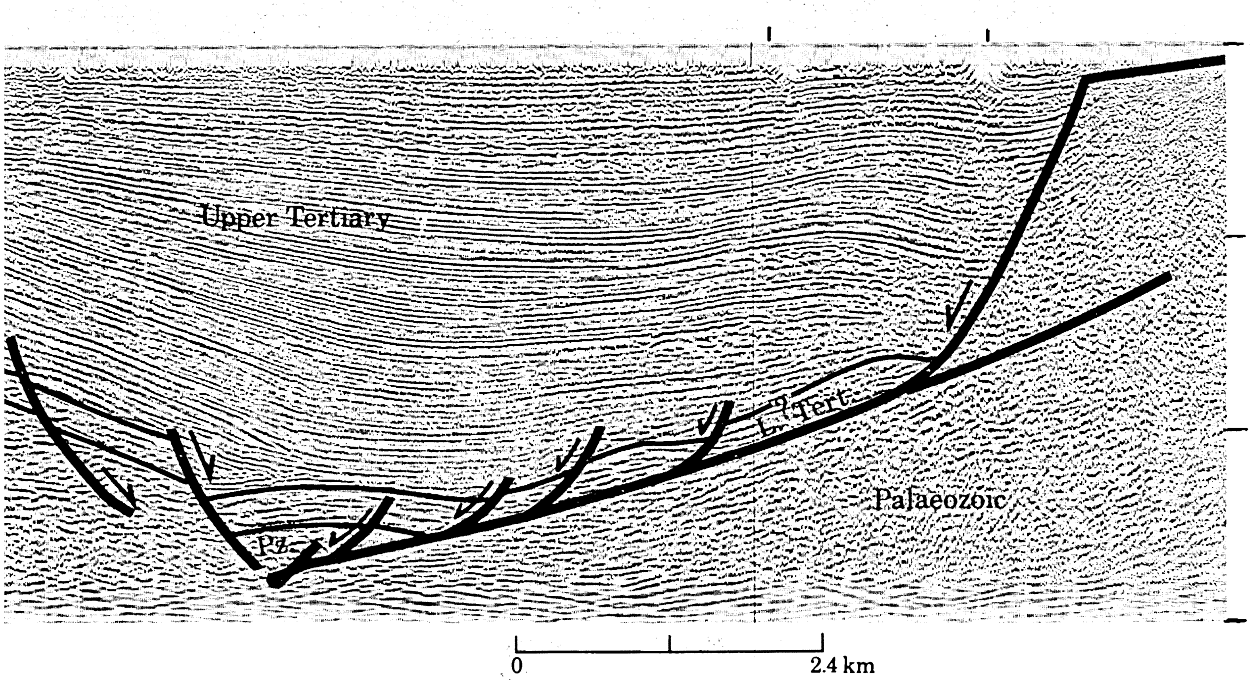

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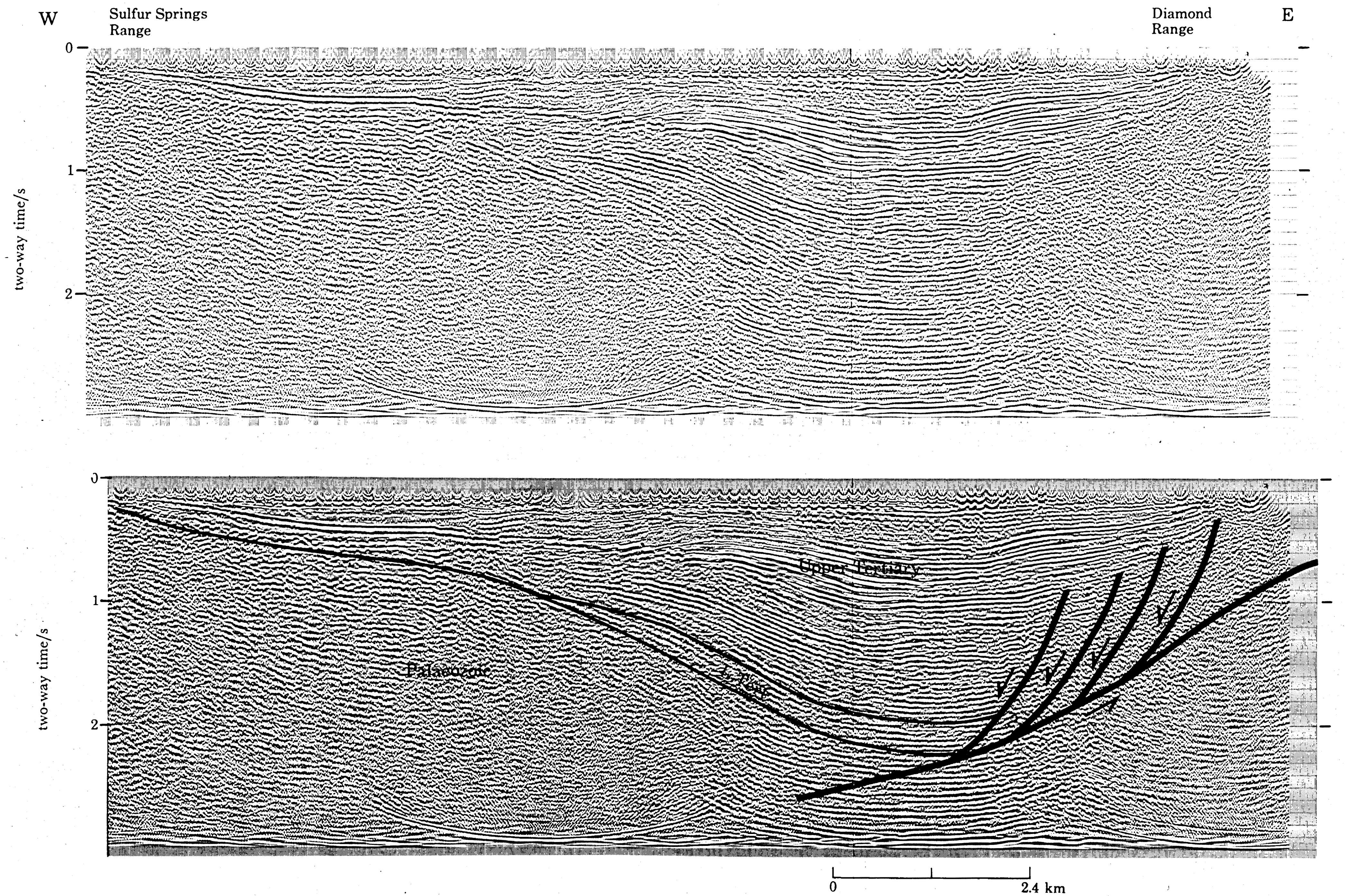

FIGURE 5. Seismic dip profile for northern Diamond Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 3.15 km.

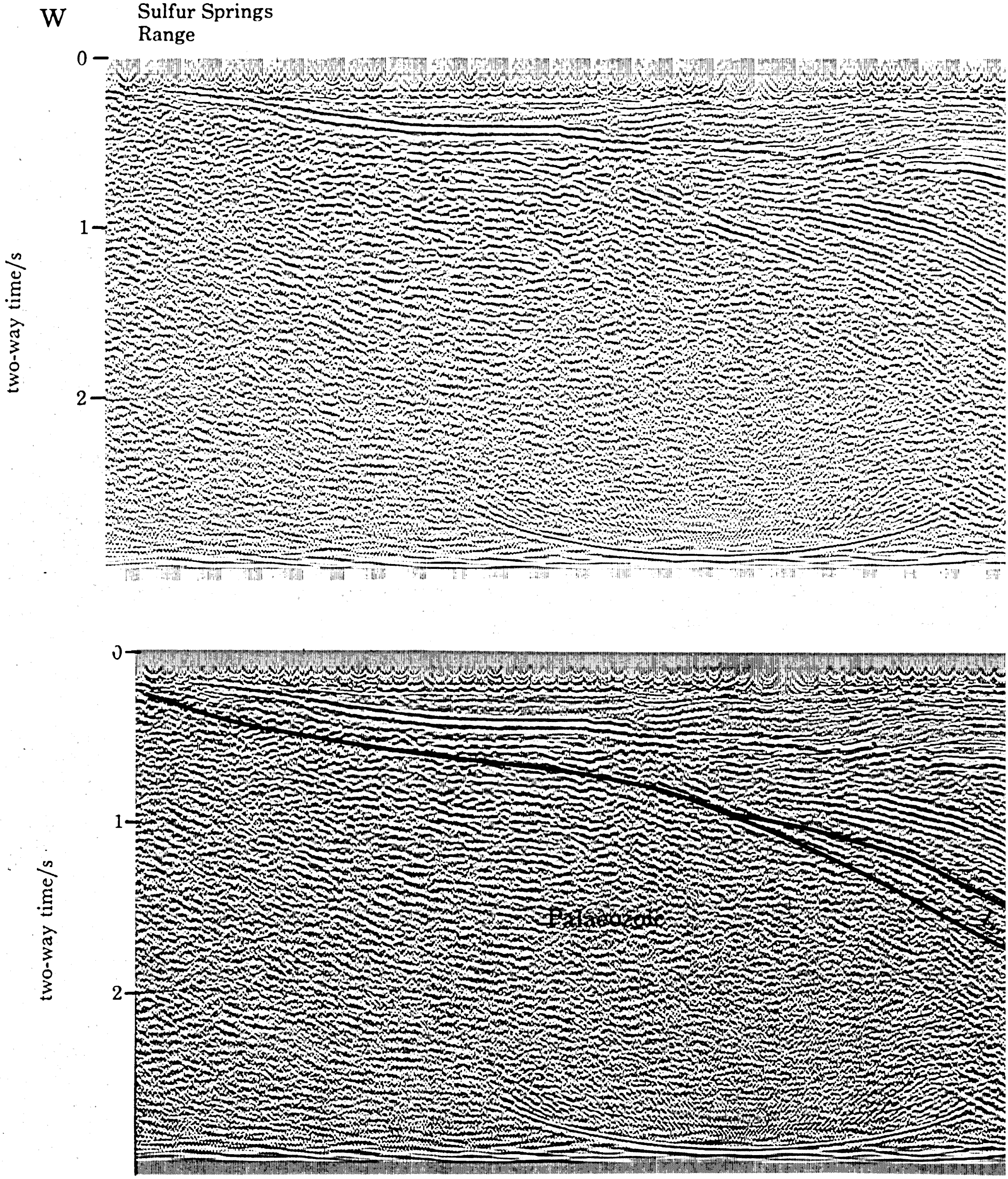

FIGURE 5. Seismic dip profile for northern Diamond Valley. D
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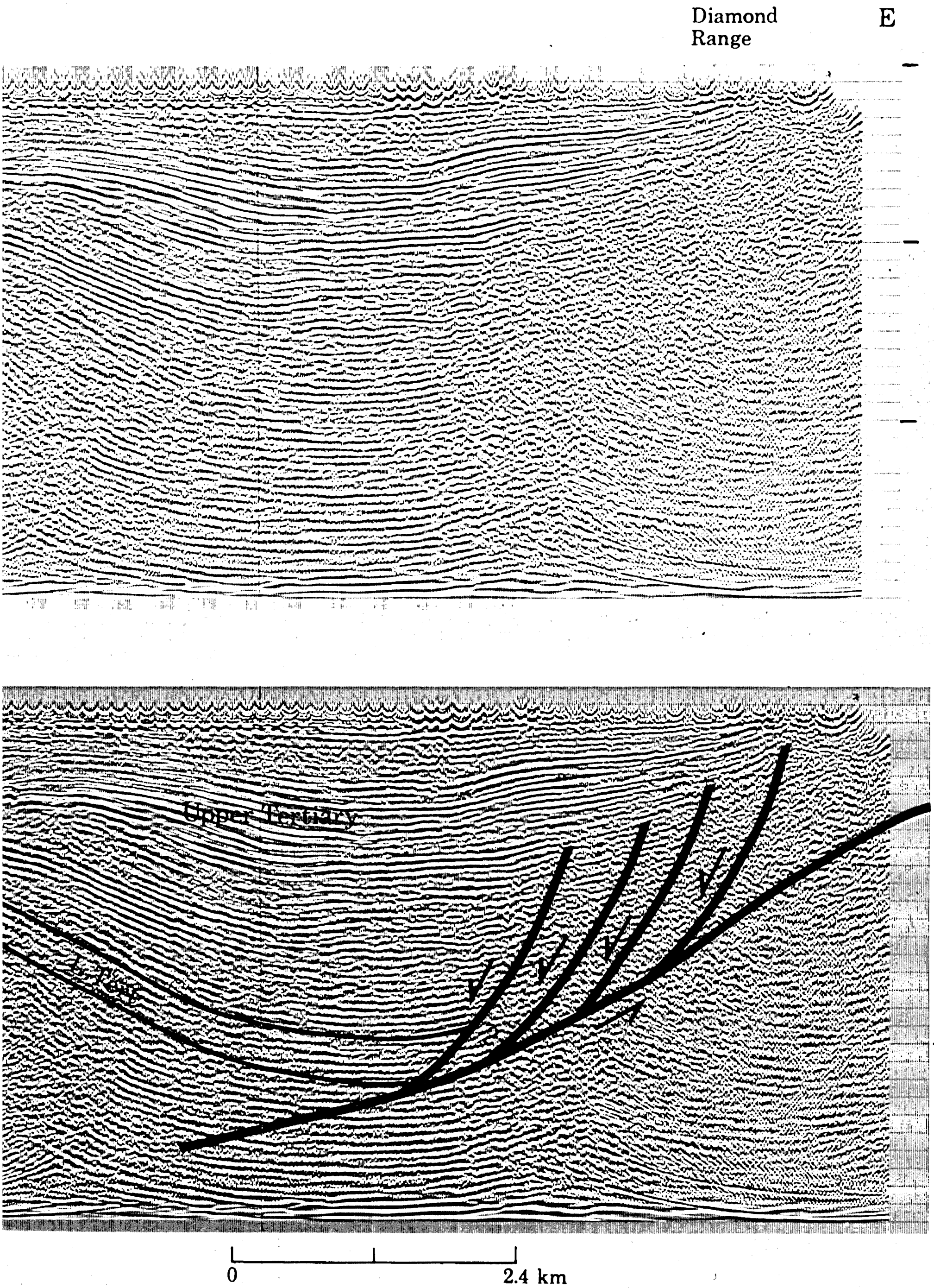

Valley. Data are 12-fold coverage, stacked, migrated and with
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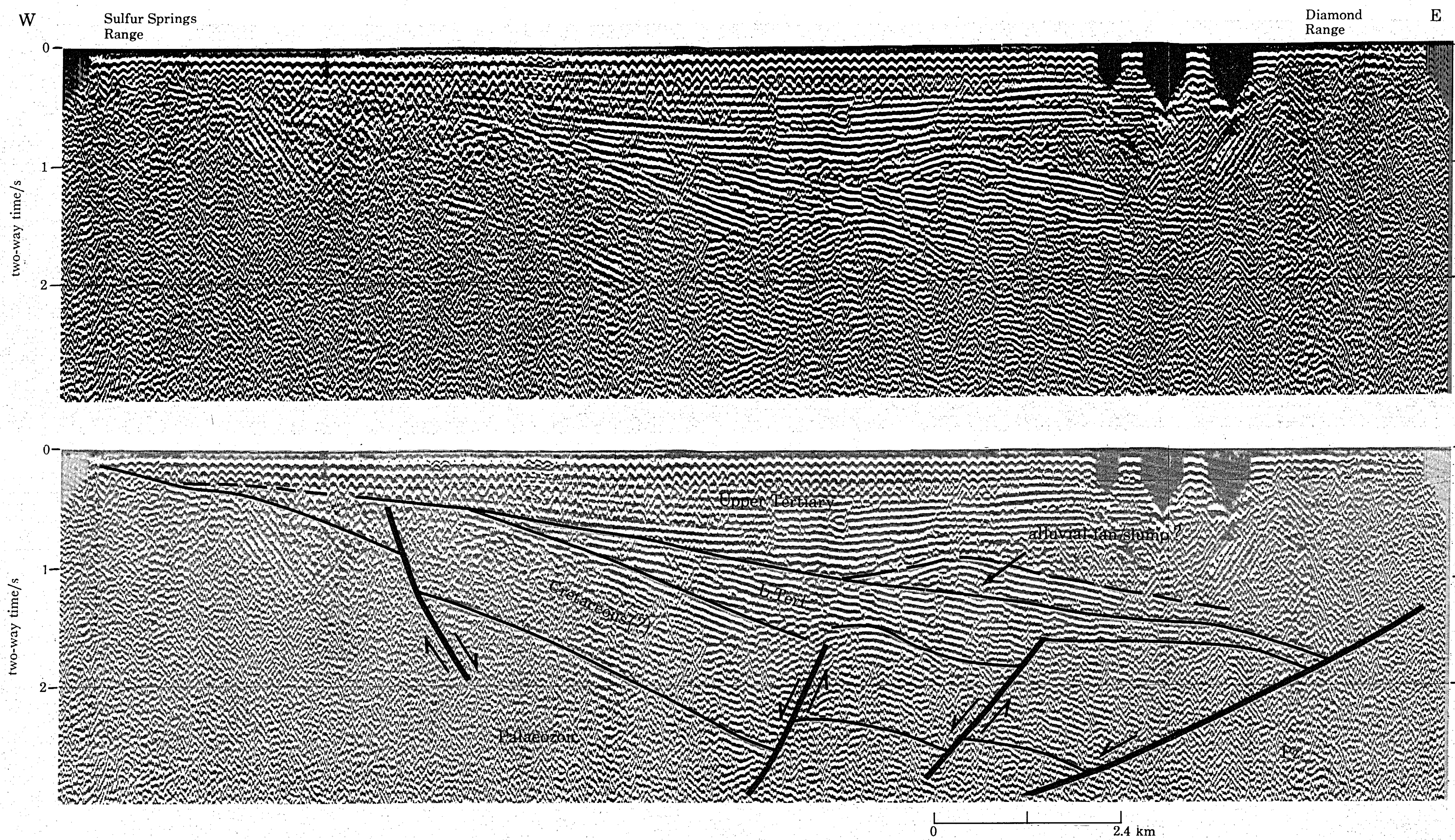


FIGURE 6. Seismic dip profile for southern Diamond Valley. Data are 12-fold coverage, stacked, with automatic statics applied and high frequencies recovered. Maximum thickness of Tertiary and Cretaceous (?) is about 4.5 km.

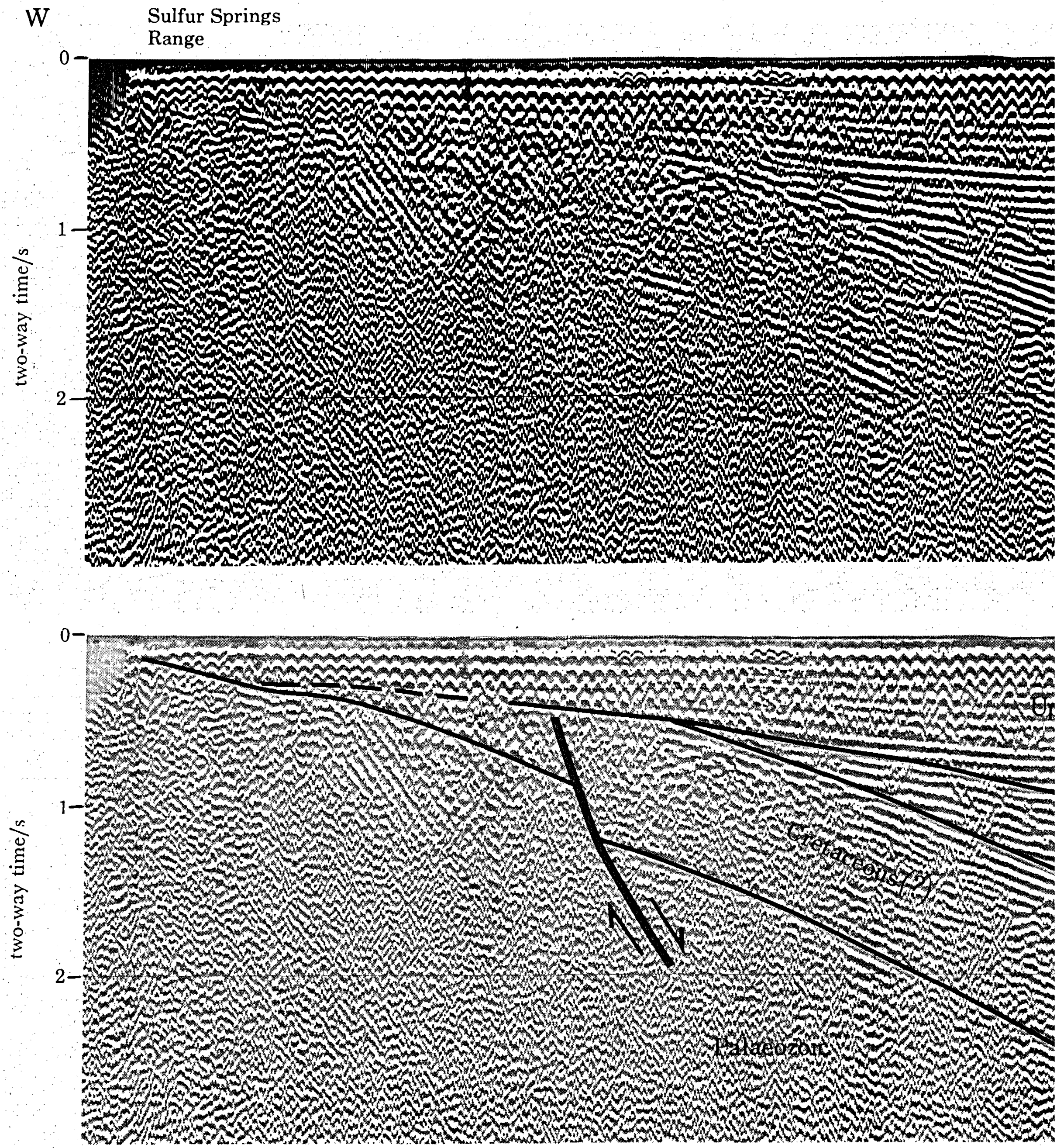
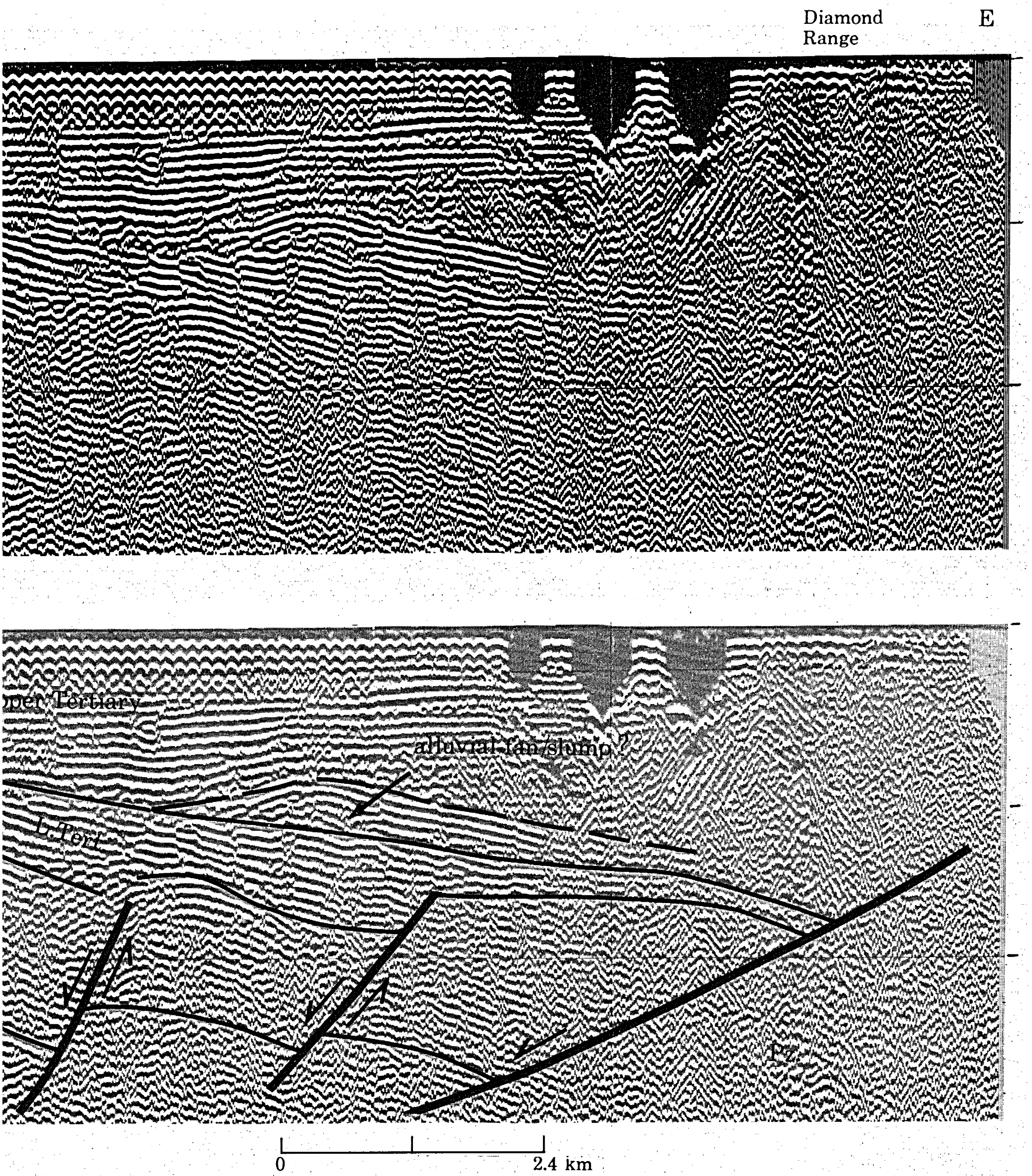


FIGURE 6. Seismic dip profile for southern Diamond Valley. Data
high frequencies recovered. Maximum thickness



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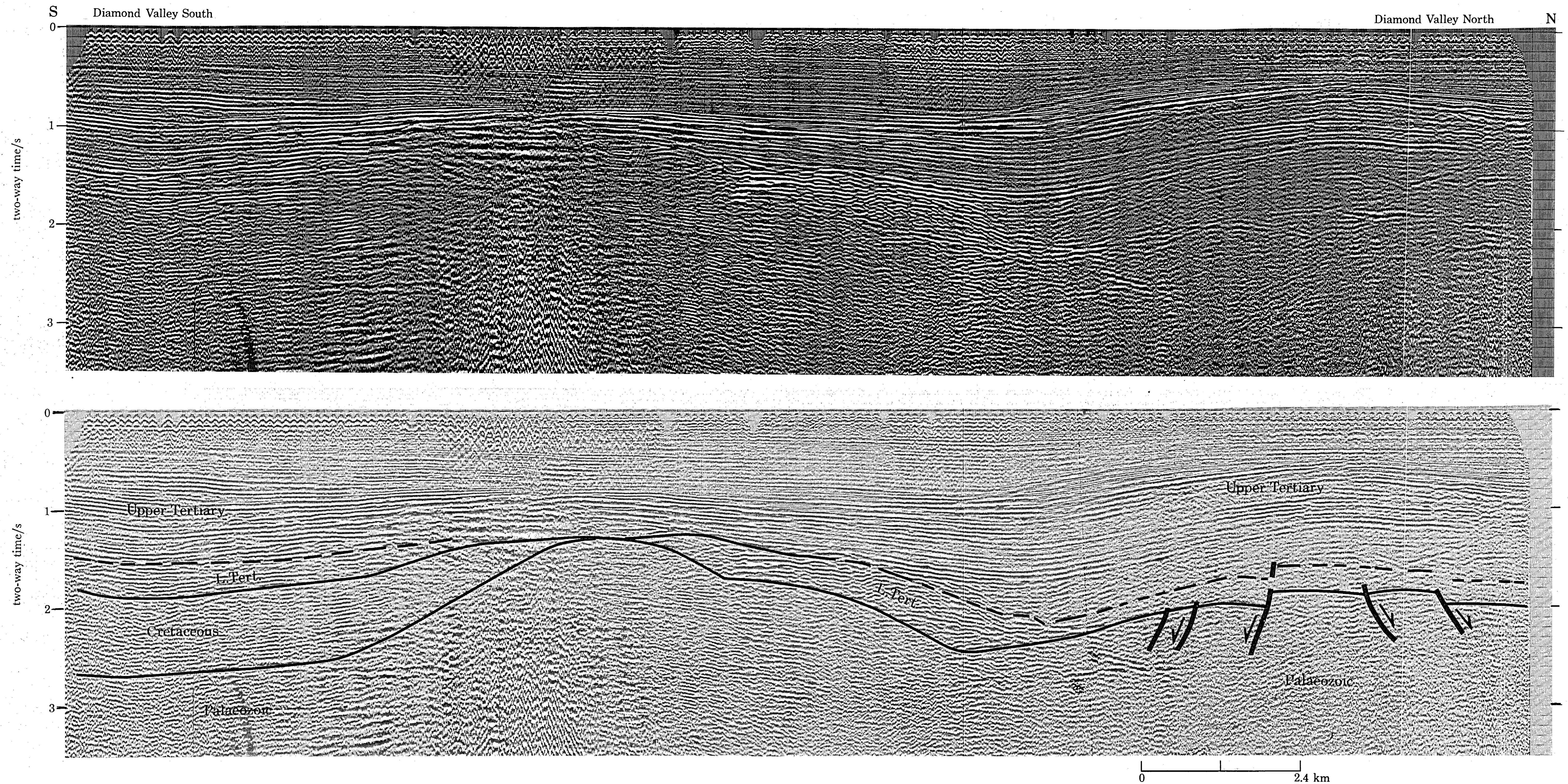
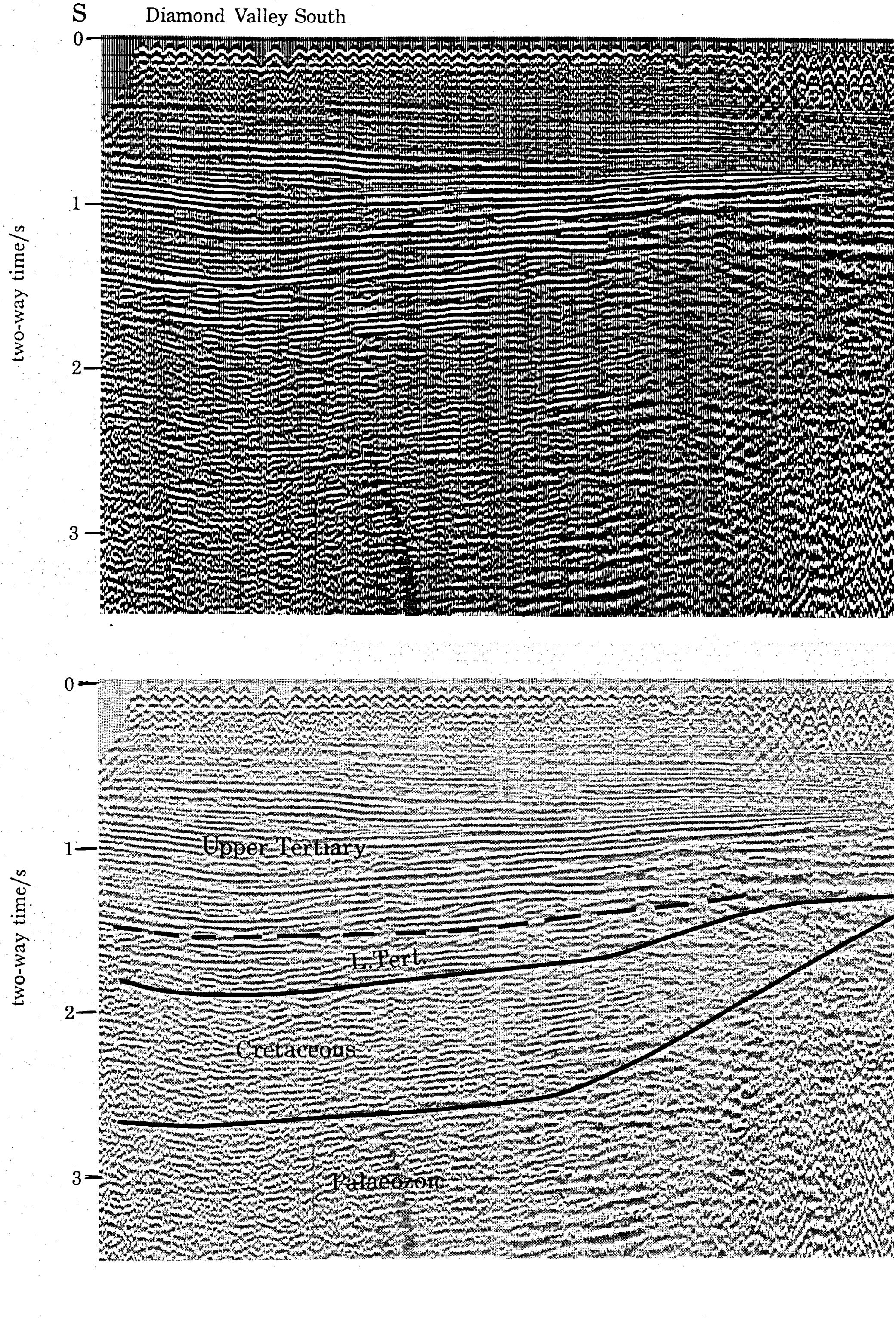


Figure 7. Seismic strike profile for Diamond Valley illustrating transverse axis and differences in stratigraphic units in the adjacent basins. Data are 12-fold coverage, stacked and with automatic statics applied.


S
Diamond Valley South
0
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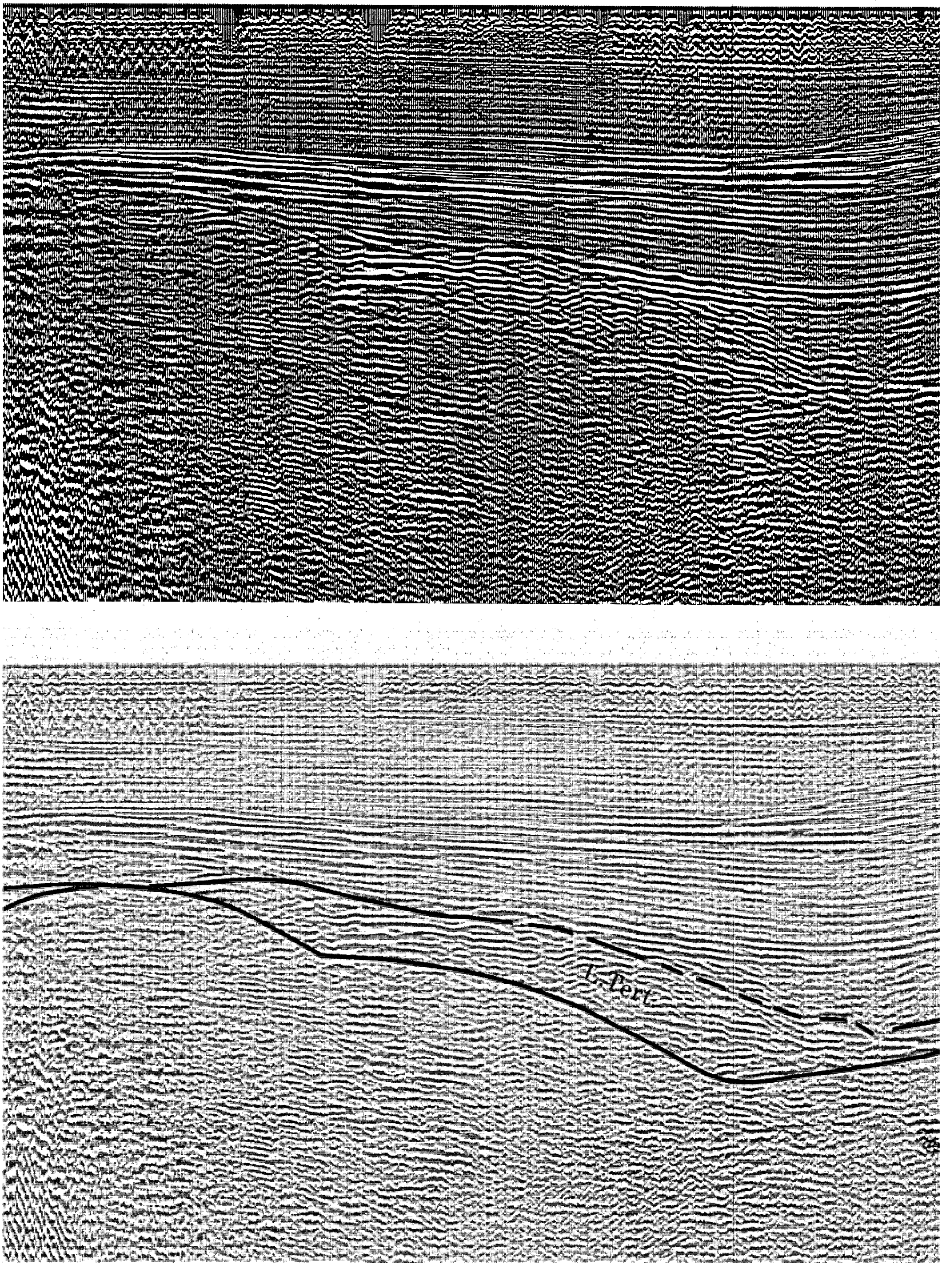
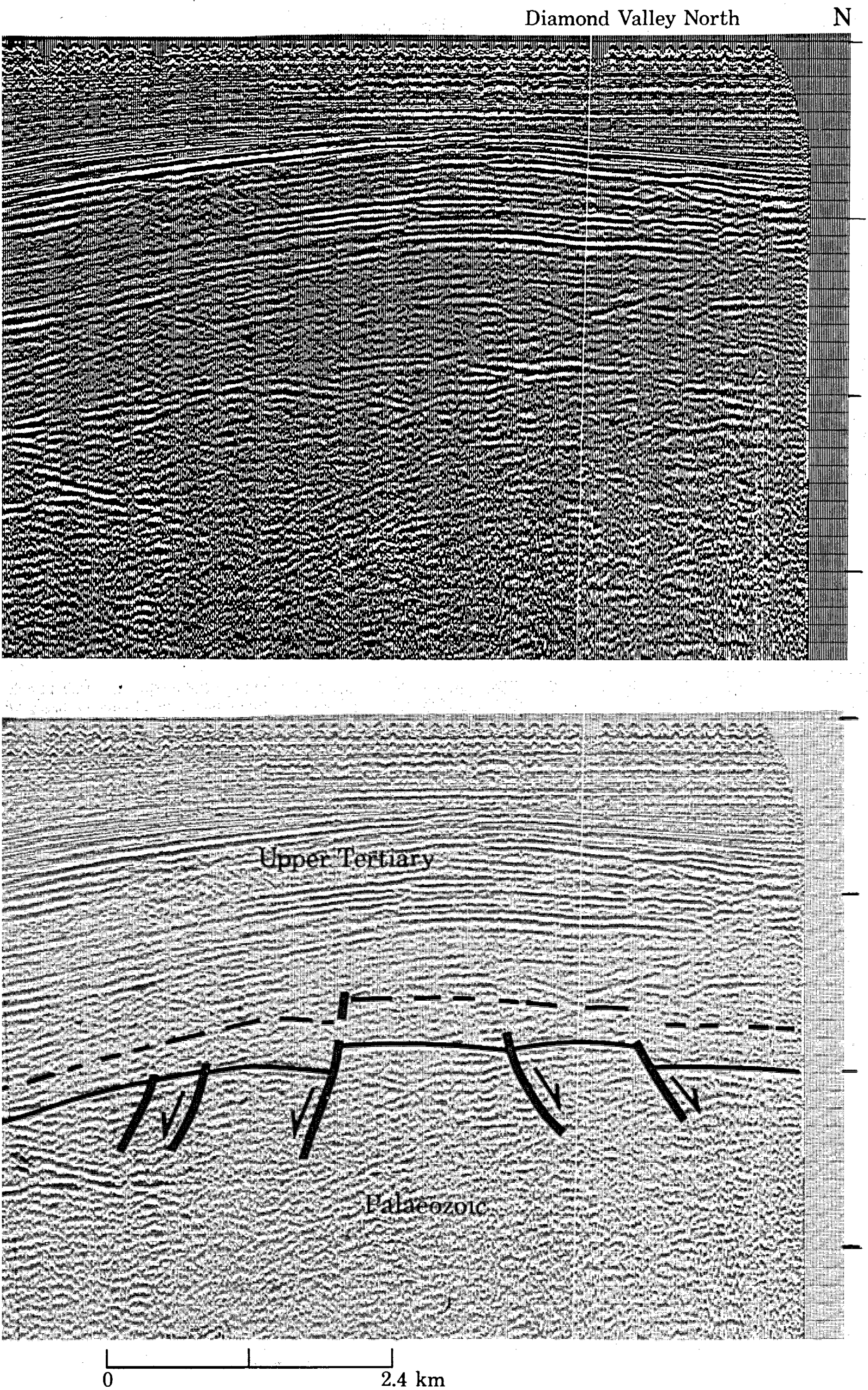
Upper Tertiary
L.Tert.
Cretaceous
Palaeozoic

FIGU



JRE 7. Seismic strike profile for Diamond Valley illustrating transverse axis and differences in stratigr
units in the adjacent basins. Data are 12-fold coverage, stacked and with automatic statics applied.



aphic

Basin development progressed at a more accelerated rate during upper Tertiary (Miocene and post-Miocene) time as evidenced by the thickness of this unit which comprises the bulk of the Tertiary section in the valley. The depocentre of each seismically discernible upper Tertiary unit migrates from west to east as slippage occurred along the low-angle listric fault. Some minor normal faulting affecting lower units of the upper Tertiary, the lower Tertiary, and Palaeozoic units in the hanging wall is interpreted to have occurred in early upper Tertiary time. The minor faulting in the eastern half of the basin is observed to sole into the low-angle listric fault. In the western half of the basin, the minor faults cannot be directly traced into the listric fault because of poor data quality. However, it is expected that the western minor normal faults behave as their eastern counterparts and also sole into the listric fault.

The seismic dip profile in figure 3 and a number of the elements covered in the description of Railroad Valley can be considered typical of most, but not all, valleys in northeastern Nevada. The four most salient attributes are listed.

1. A westward-dipping listric fault bounds the valley to the east.

2. A gentle eastward-dipping western flank of the basin is in a hanging wall relation to the listric fault.

3. The basin is asymmetric as defined by the Tertiary sediments with its depocentre adjacent to the listric fault.

4. The upper Tertiary (Miocene and post-Miocene) depocentres migrate from west to east through time in response to movement along the listric fault.

Diamond Valley

Interpretation of the seismic profiles at Diamond Valley is based primarily on the seismic character of reflexion packages that can be correlated with stratigraphic units in adjacent valleys where both well and seismic data exist. Outcrop data were also used in interpretation of the seismic profiles. Stratigraphic control for the Tertiary section at Diamond Valley is virtually non-existent as the only well drilled in the basin at the time of this study penetrated an anomalous unit and therefore cannot be used for correlation.

The seismic dip profiles across northern Diamond Valley and southern Diamond Valley (figures 5 and 6, pullouts 2 and 3, respectively) indicate a general similarity to the seismic dip profile across Railroad Valley (figure 3). Furthermore, there is a similarity in the overall thickness of the Tertiary package which ranges from about 3.0–4.5 km. In terms of the four salient attributes listed in the previous section, northern Diamond Valley is more similar to Railroad Valley than it is to southern Diamond Valley. Quality seismic data are difficult to obtain along the eastern flank of Diamond Valley owing to the presence of thick alluvial fans and slumps; the seismic reflexion generated by the listric fault is thus partly downgraded by noise.

Dissimilarities between the northern and southern Diamond Valley exist primarily in the timing and/or rate of deformation, as well as its inferred depositional history. Southern Diamond Valley (figure 6) contains a thinner upper Tertiary unit, a thicker lower Tertiary unit, and possibly even a Cretaceous unit. The Cretaceous unit possibly present in southern Diamond Valley may be the Newark Canyon Series observed in the outcrop of the Diamond Range, which flanks the valley to the east. It is suggested that during Cretaceous time the area occupied by southern Diamond Valley was structurally lower than northern Diamond Valley and thus received Newark Canyon Sediments. The lower Tertiary unit in southern Diamond Valley was deposited in a more deformed basin than the same unit in northern Diamond Valley based on its thickness variations. This suggests an earlier episode of basin formation or a more rapid history of basin subsidence in the south than in the north. The upper Tertiary units in northern Diamond Valley are much thicker than to the south during that time.

The differing behaviour of the northern and southern portions of Diamond Valley is shown in figure 7, pullout 4, which is a north–south seismic strike profile. The most prominent feature on the profile is the large mass of Palaeozoic located approximately to the left of centre on the figure. In three dimensions, this Palaeozoic mass is mapped as an east–west axis separating Diamond Valley into two distinct sub-basins with different timing and/or rate of deformation as well as differing stratigraphy. The origin of the axis is postulated to be the result of a tear fault associated with the differential movement along the westward-dipping listric fault which, as in Railroad Valley, probably utilized décollement surfaces within the Palaeozoic sedimentary section. Differences in the timing and/or rate of movement of the listric fault caused the Palaeozic units in the hanging wall along the tear fault to deform almost chaotically. At the time of this study, the only well in Diamond Valley, the Shell Diamond Valley no. 1, drilled in 1956, penetrated the axis and recovered brecciated, chloritized Palaeozoic rocks suggestive of a shear zone.

Transverse elements, as described in Diamond Valley, can be documented for other valleys in northeast Nevada with sufficient geological and geophysical data; however, the subsurface structural relief of the axes varies from valley to valley. Probably in most cases, the deformational history of each sub-basin within any given valley will be different.

Mary's River Valley

The seismic dip profile for Mary's River Valley exhibits all the four salient attributes of valleys in northeastern Nevada summarized in the section on Railroad Valley. The factor that sets this valley apart from those previously discussed is that the westward-dipping listric fault appears to sole in a mylonitic crystalline rock at the base of the unmetamorphosed Palaeozoic sedimentary section rather than into décollement surfaces within the Palaeozoic sedimentary section. The description and possible origin for the mylonite zone are discussed by Misch (1960) and Snelson (1957). The zone crops out in the Ruby and East Humboldt Ranges that bound Mary's River Valley to the east and can be correlated into the seismic profile in the valley (figure 8, pullout 5). Stratigraphic control for interpreting the seismic profile in figure 8 was obtained from well data available updip on the western flank of the basin and outcrop information (Howard 1971; Stewart & Carlson 1978). The absence of good reflectors prevents the separation of the lower Tertiary from the Palaeozoic units in the hanging wall and thus details on the time of basin development initiation are absent. It also precludes the seismic determination of the total Tertiary thickness. Magnetotelluric and gravity surveys, however, suggest a maximum depth to top Palaeozoic of 2.4 km.

Minor normal faulting observed in Mary's River Valley is of a much younger age (upper and post-Miocene) than in the other valleys discussed. In the other valleys, the upper Tertiary is virtually unfaulted. The minor faults in Mary's River Valley sole into the low-angle listric fault as observed in Railroad Valley (figure 3).

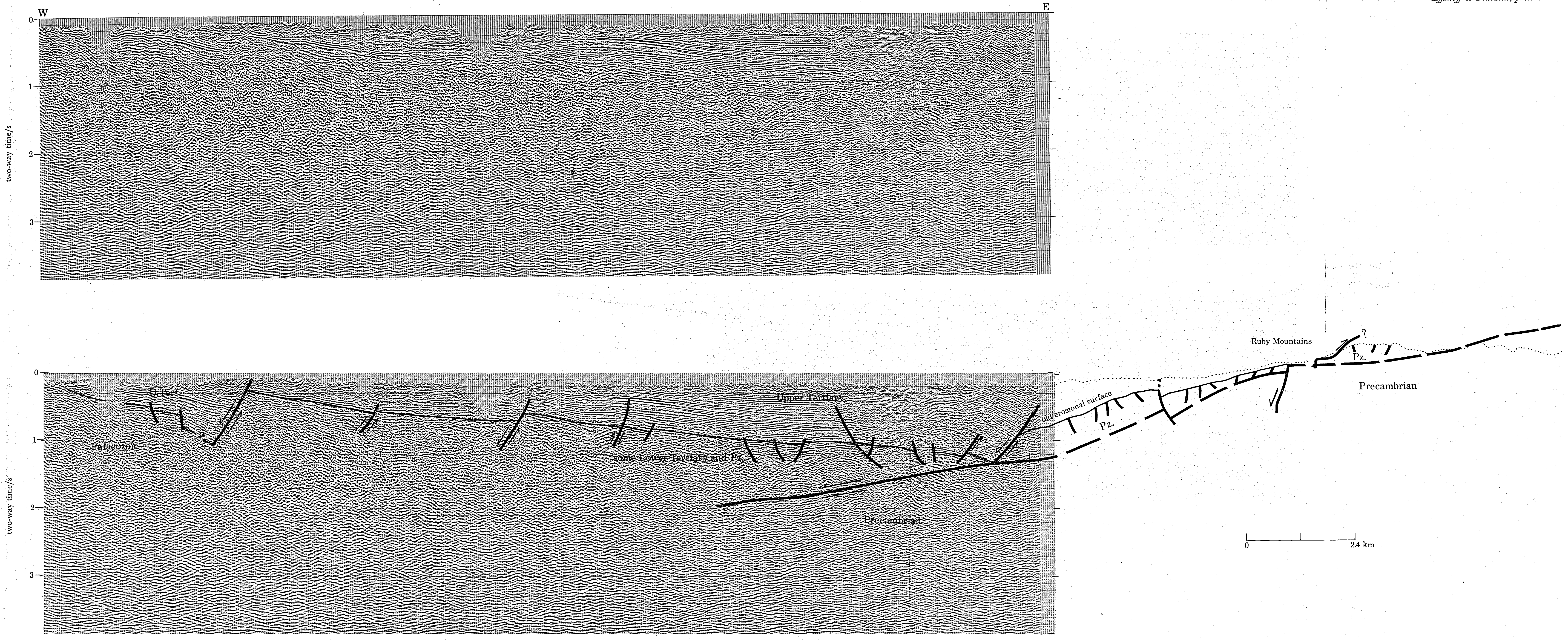
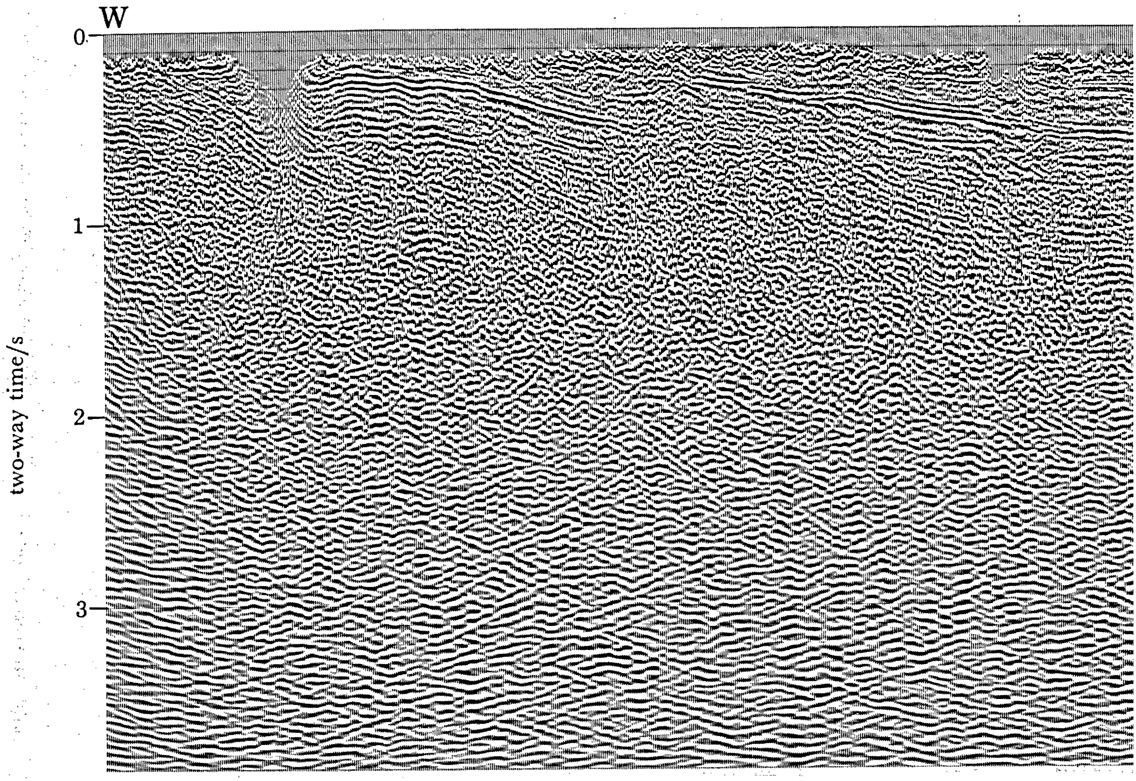


FIGURE 8. Seismic dip profile for Mary's River Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 2.4 km.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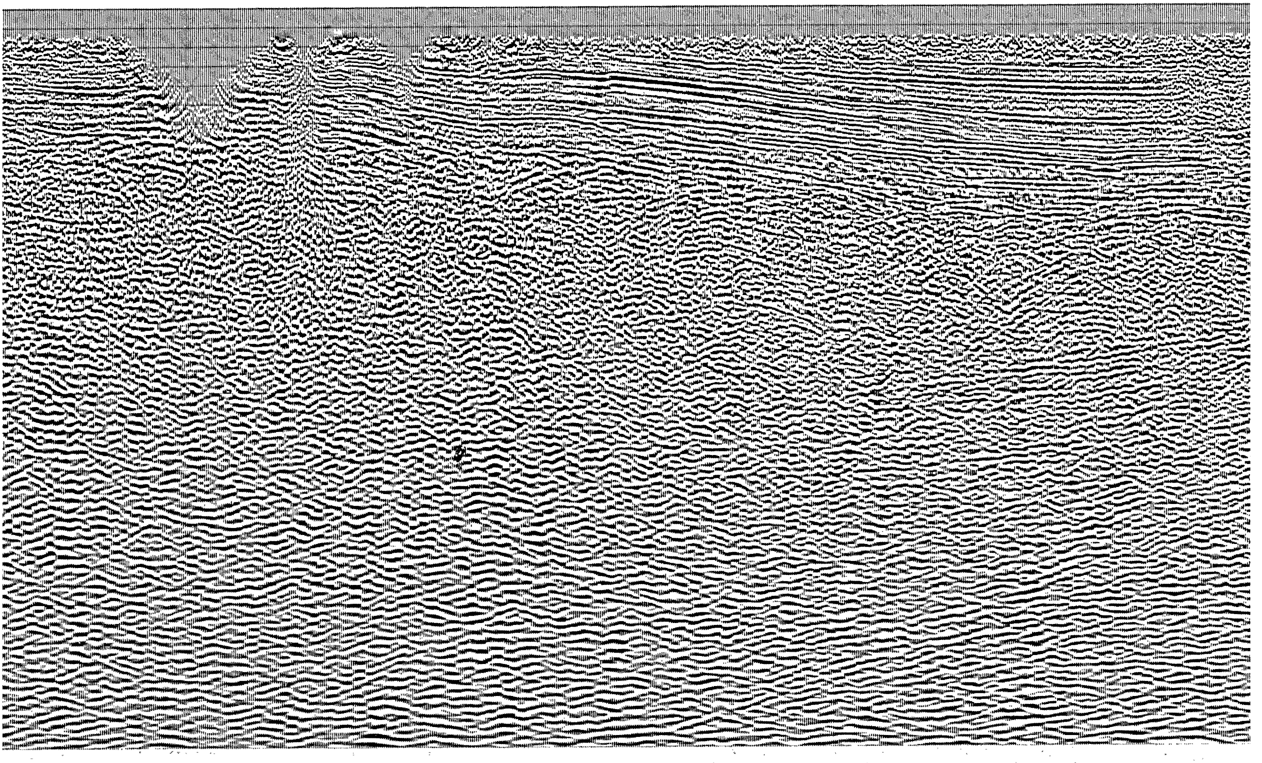

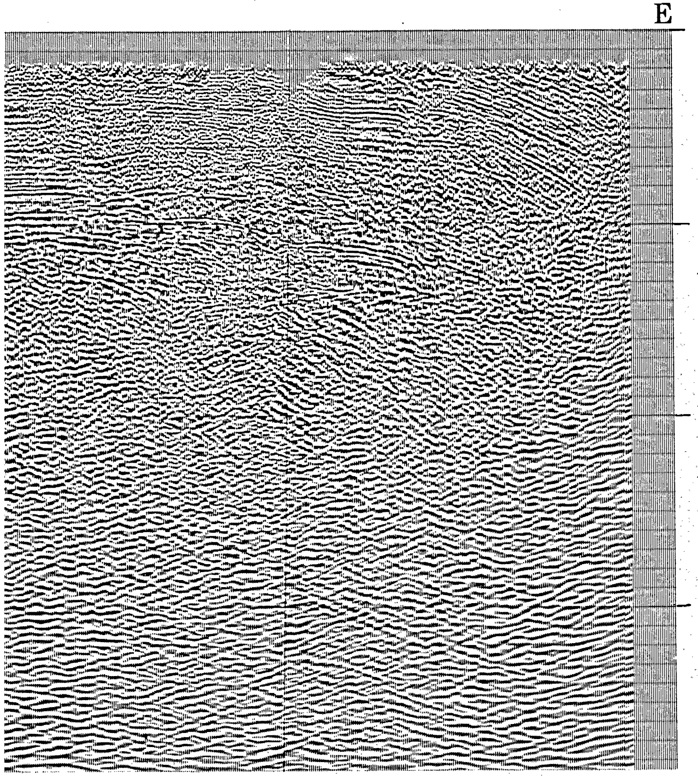

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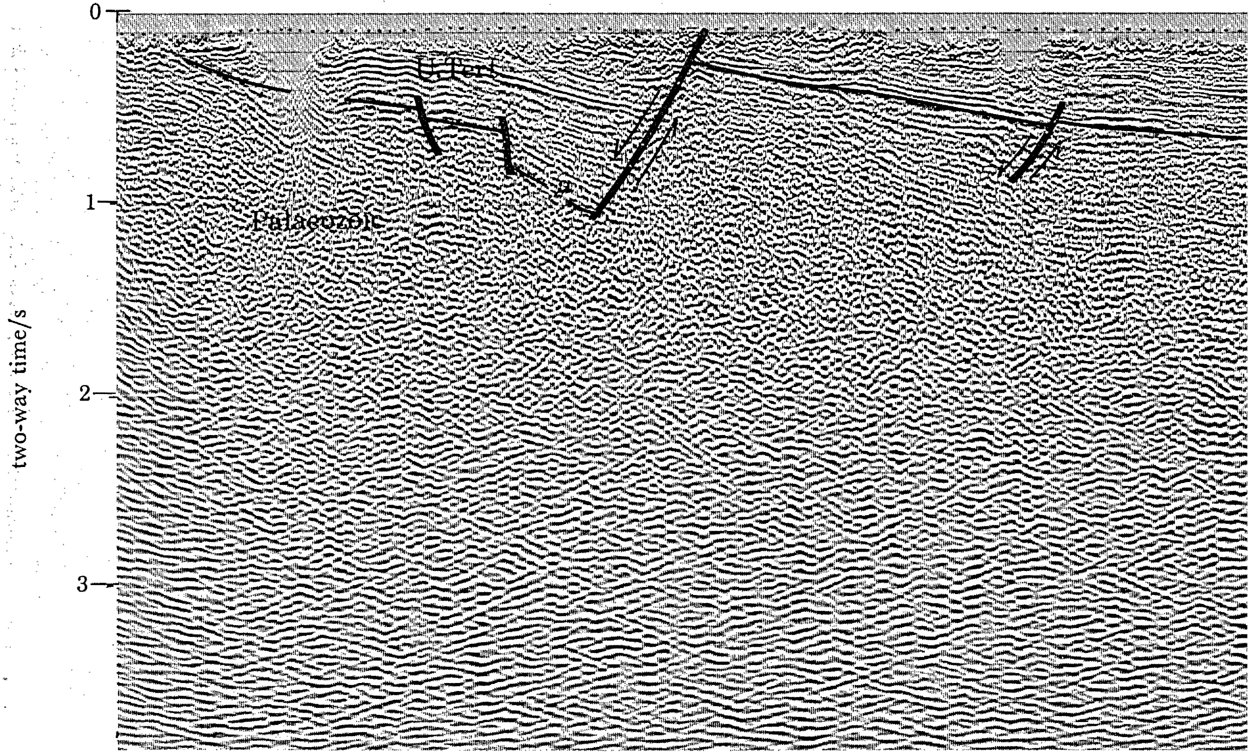
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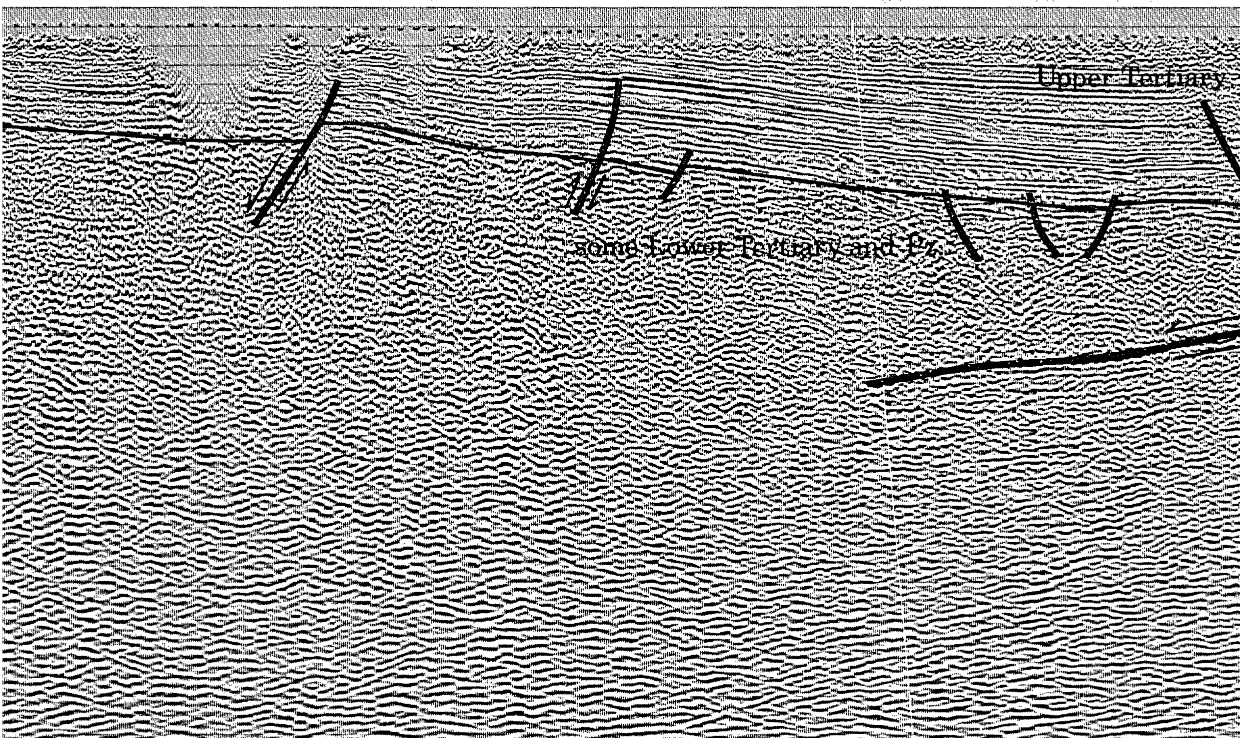

FIGURE 8. Seismic dip profile for Mary's River Valley. Data are 12-fold c
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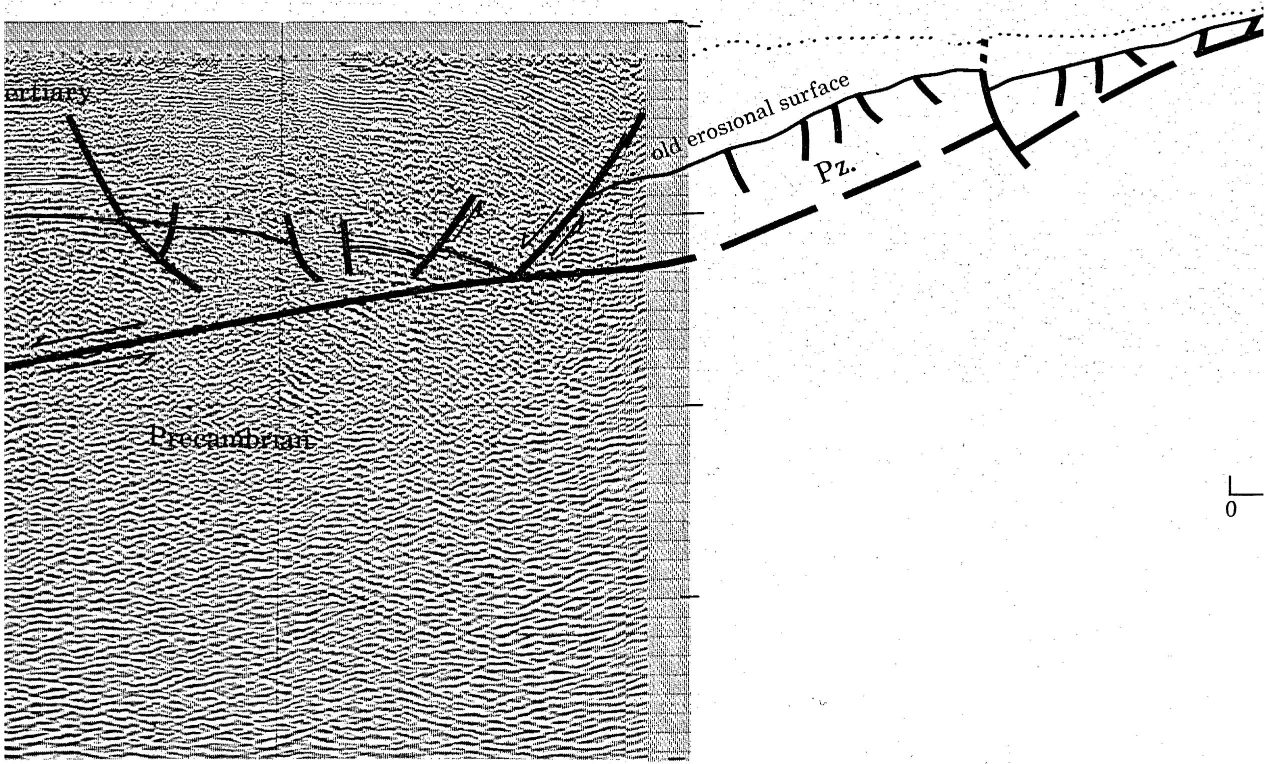

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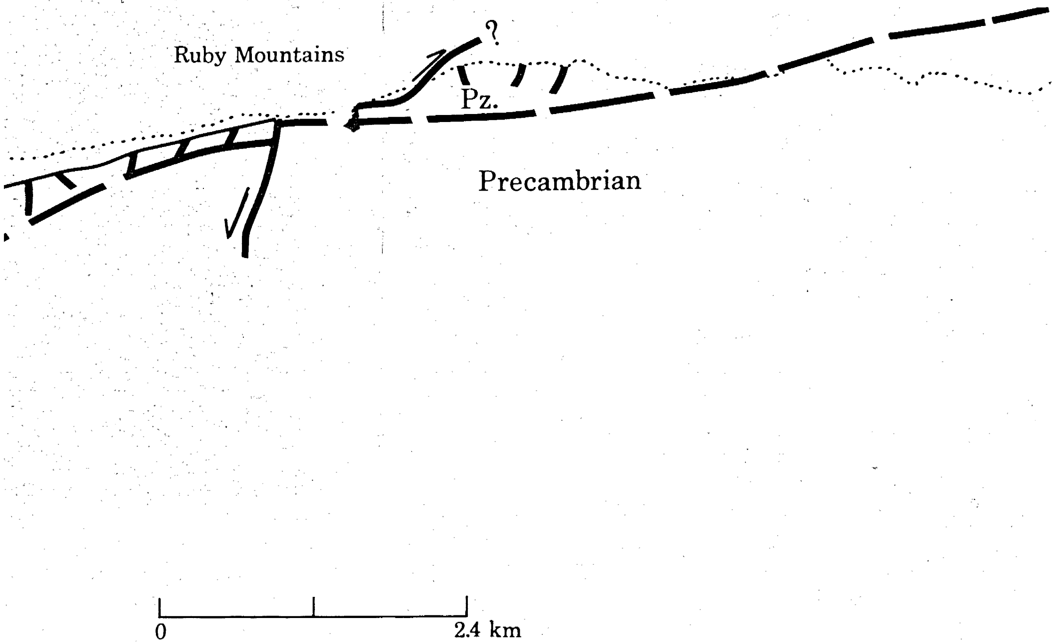
ss of Tertiary is about 2.4 km.



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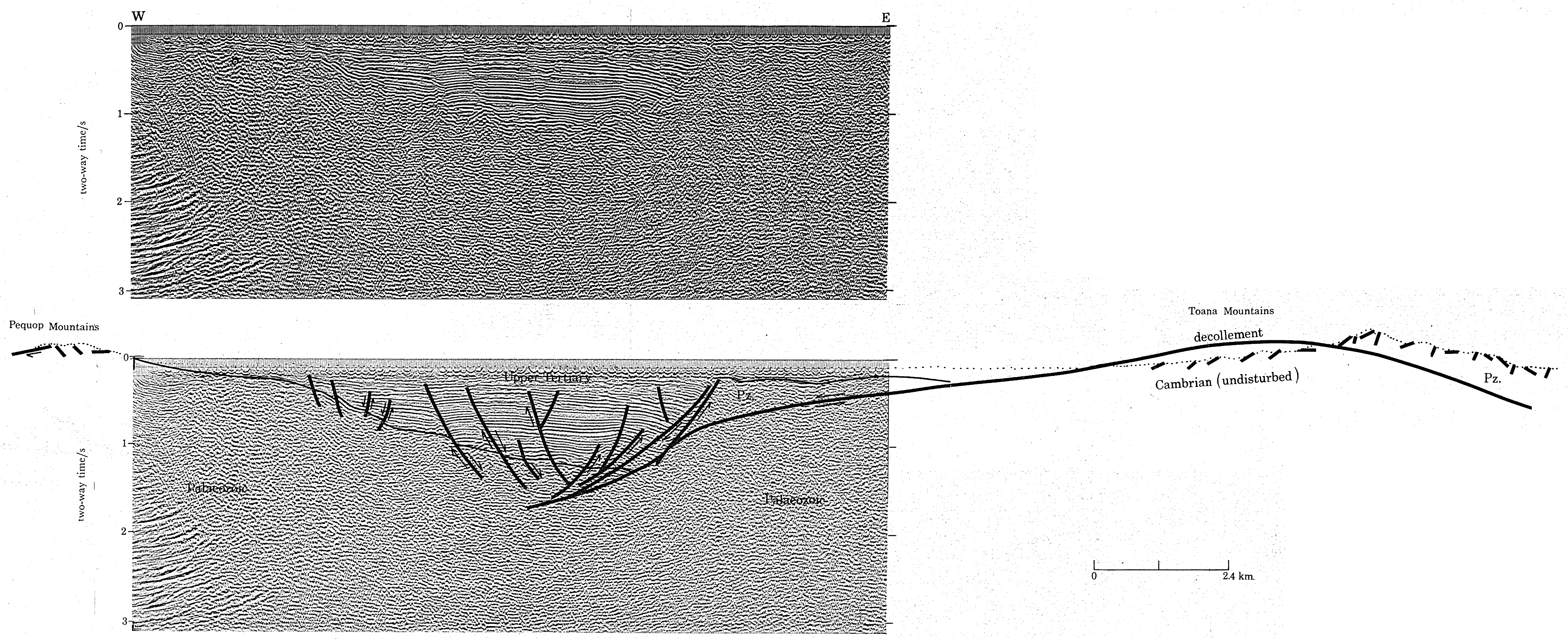
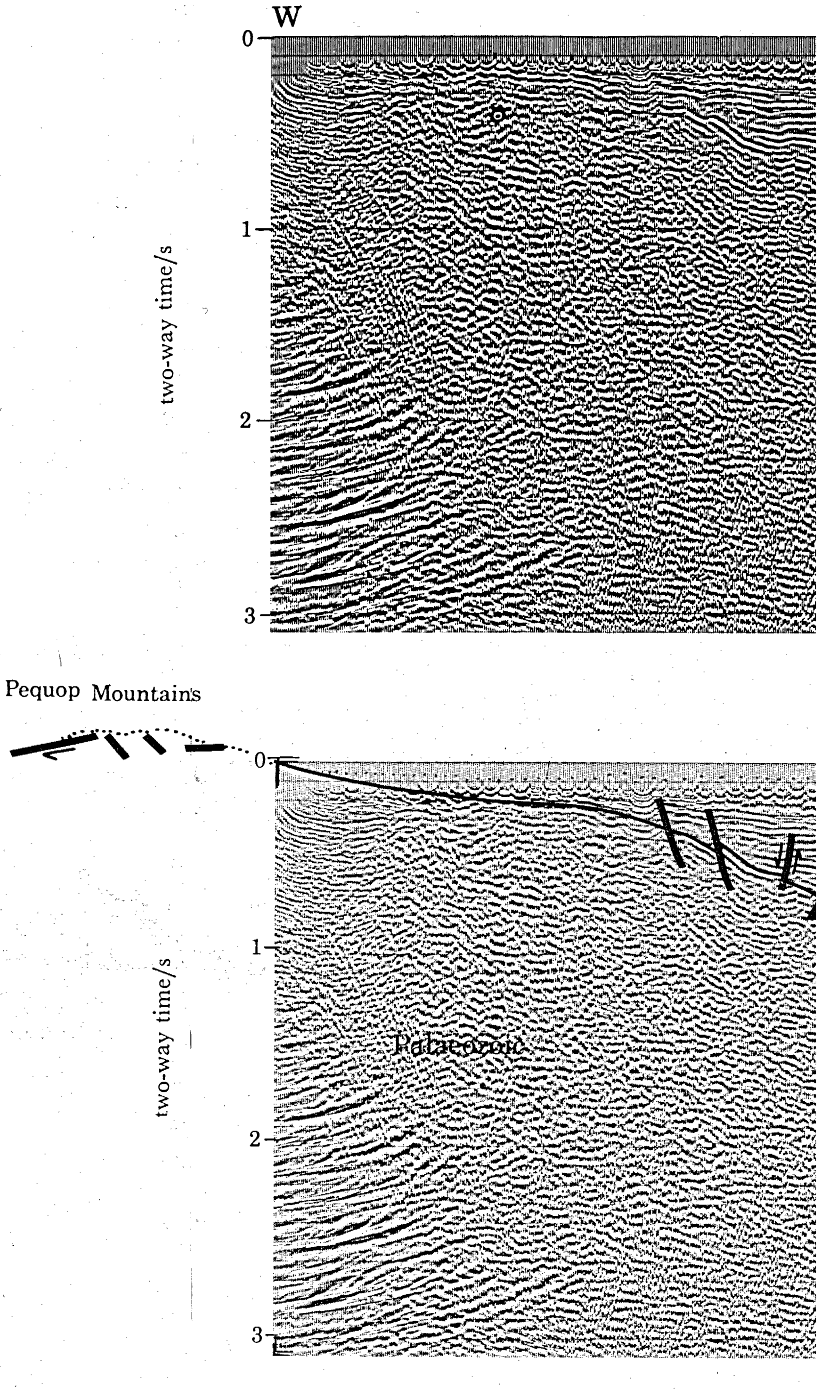


FIGURE 9. Seismic dip profile for Goshute Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 2.7 km.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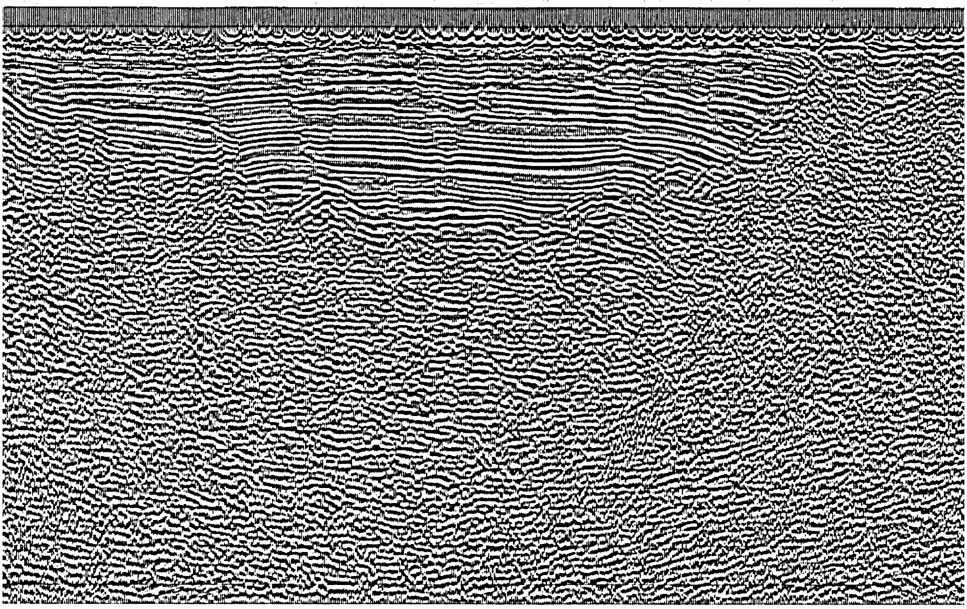
Palaeozoic



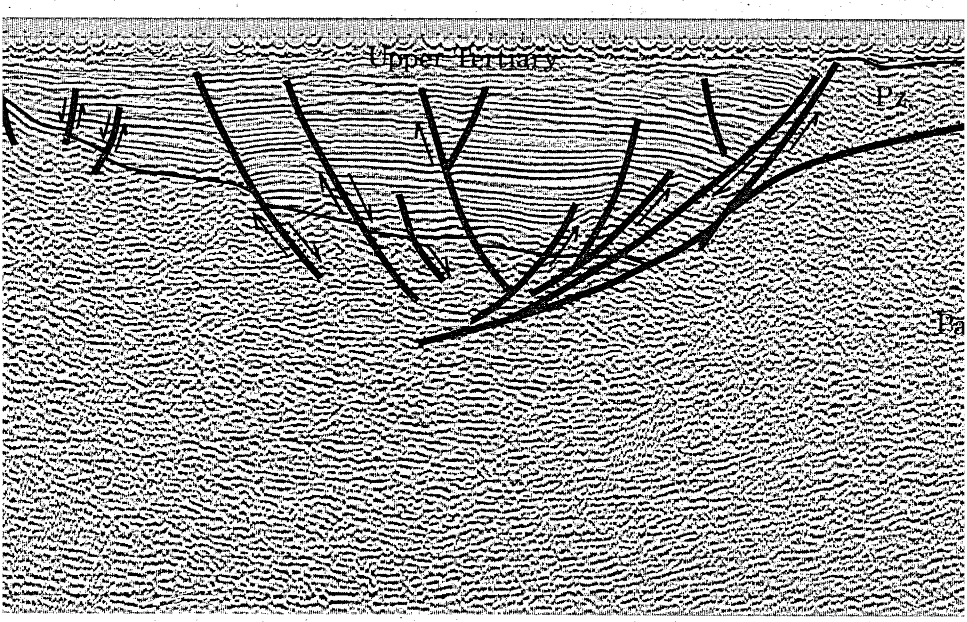


FIGURE 9. Seismic dip profile for Goshute
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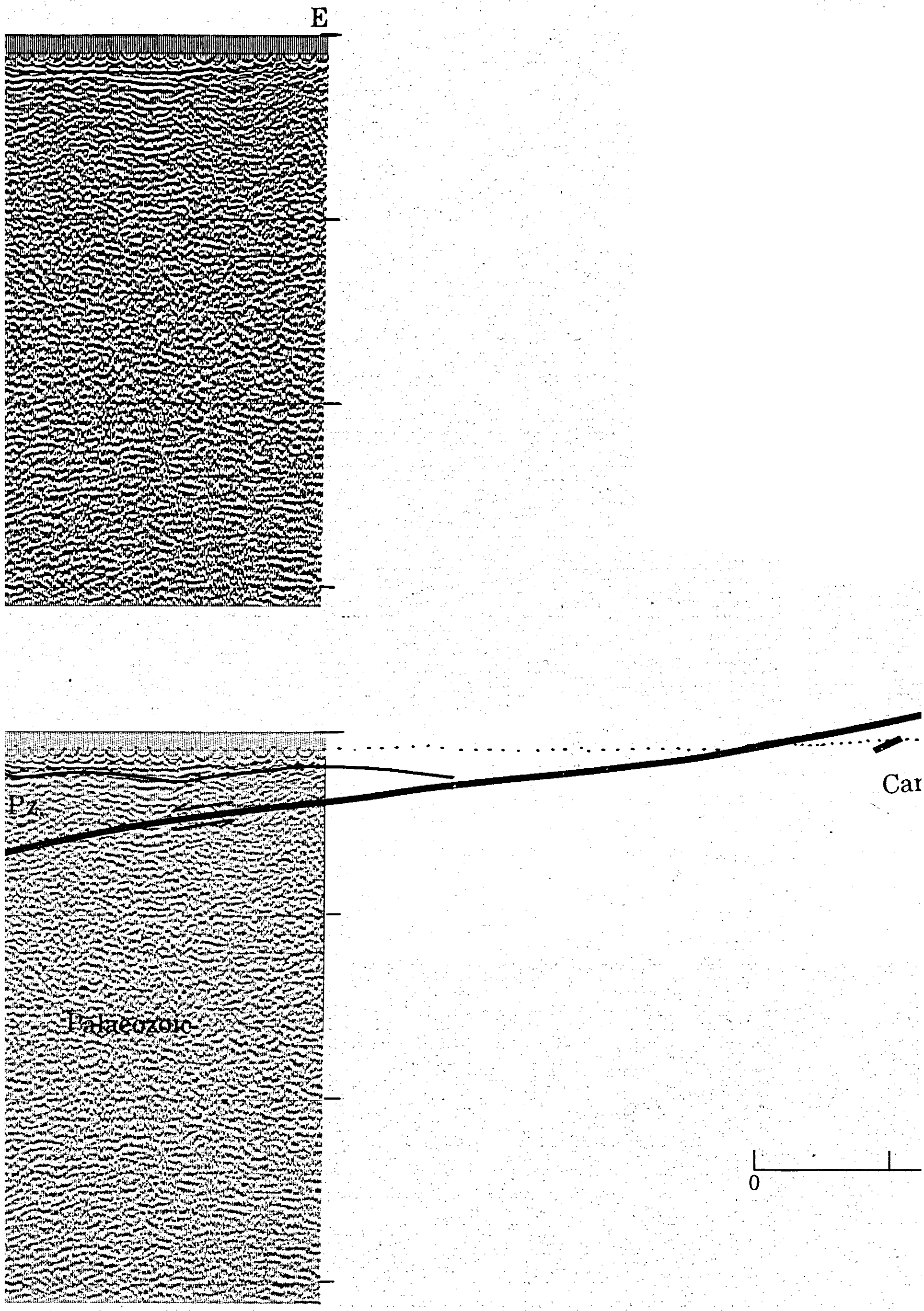

Goshute Valley. Data are 12-fold coverage, stacked, migrated and with automatic
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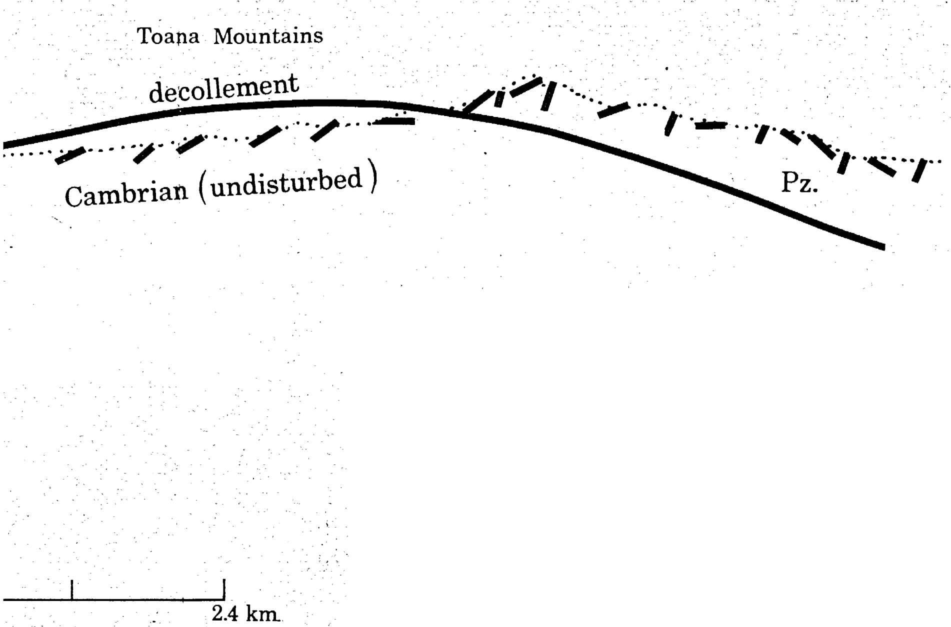
Toana Mountains
decollement
Cambrian (undisturbed)
Pz.
2.4 km.

Goshute Valley

Goshute Valley (figure 9, pullout 6) is similar to other valleys discussed based on the four attributes of these valleys previously summarized. The lower Tertiary present in all the other valleys discussed is absent at Goshute Valley. A well drilled in the centre of the basin encountered upper Tertiary units directly overlying the Palaeozoic. It is therefore suggested that the area in which this valley was located was structurally positive during lower Tertiary time and may even have served as a source for clastics to the adjacent areas. Goshute Valley did not become a basin until upper Tertiary time, when it accumulated about 2.7 km of sediments.

Conclusion

Railroad, Diamond, Mary's River and Goshute Valleys in the Basin and Range province of northeastern Nevada were studied to establish similarities and differences in their Tertiary structural development. Documentation for the study was provided by integrating seismic data with well and outcrop information.

All the valleys studied contain a Tertiary section which, in dip section, defines an asymmetrical basin bounded on the east flank by a major listric fault. Displacement along the listric fault varies from valley to valley but is usually 3 km with a range of 2.4 to 4.5 km. The western flank of the basin is defined by a gently eastward-dipping ramp. Seismically, the trace of the westward dipping listric fault is generally interpreted to sole into décollement surfaces in the Palaeozoic sedimentary section or locally into a mylonite zone at the base of the unmetamorphosed Palaeozoic sedimentary section. The stratigraphic position of the décollement surfaces utilized by the listric fault cannot be established in every valley. The Tertiary depocentre adjacent to the bounding fault shifted from west to east with continued slippage on the listric fault through time. The greatest rate of movement along the listric fault generally occurred in upper Tertiary (Miocene and post-Miocene) time; however, basin formation in most but not all valleys was initiated in lower Tertiary time.

In the strike direction, the valleys are usually separated into two sub-basins by an east–west structurally high axis. The trend is postulated to be the result of a tear fault system in the hanging wall associated with differential movement along portions of the listric normal fault.

Thickness in Tertiary stratigraphic units vary between valleys and between sub-basins in a given valley. All valleys contain upper Tertiary rocks; however, not all sub-basins contain the lower Tertiary section, suggesting a complex scheme of structural development in this small portion of the Basin and Range province.

We should like to express our gratitude to the Shell Oil Company for their permission to release for publication the seismic lines and information contained within this paper. Special thanks go to A. W. Bally who, with S. Snelson, suggested the preparation of this paper and served as constructive critics and to F. B. Conger who provided many insights into the geology of the region. Particular acknowledgement is due to R. Mason who was among the first to make many of the observations reported. We are also grateful to D. Preston, W. Winfrey and J. Kruger, for many stimulating discussions.

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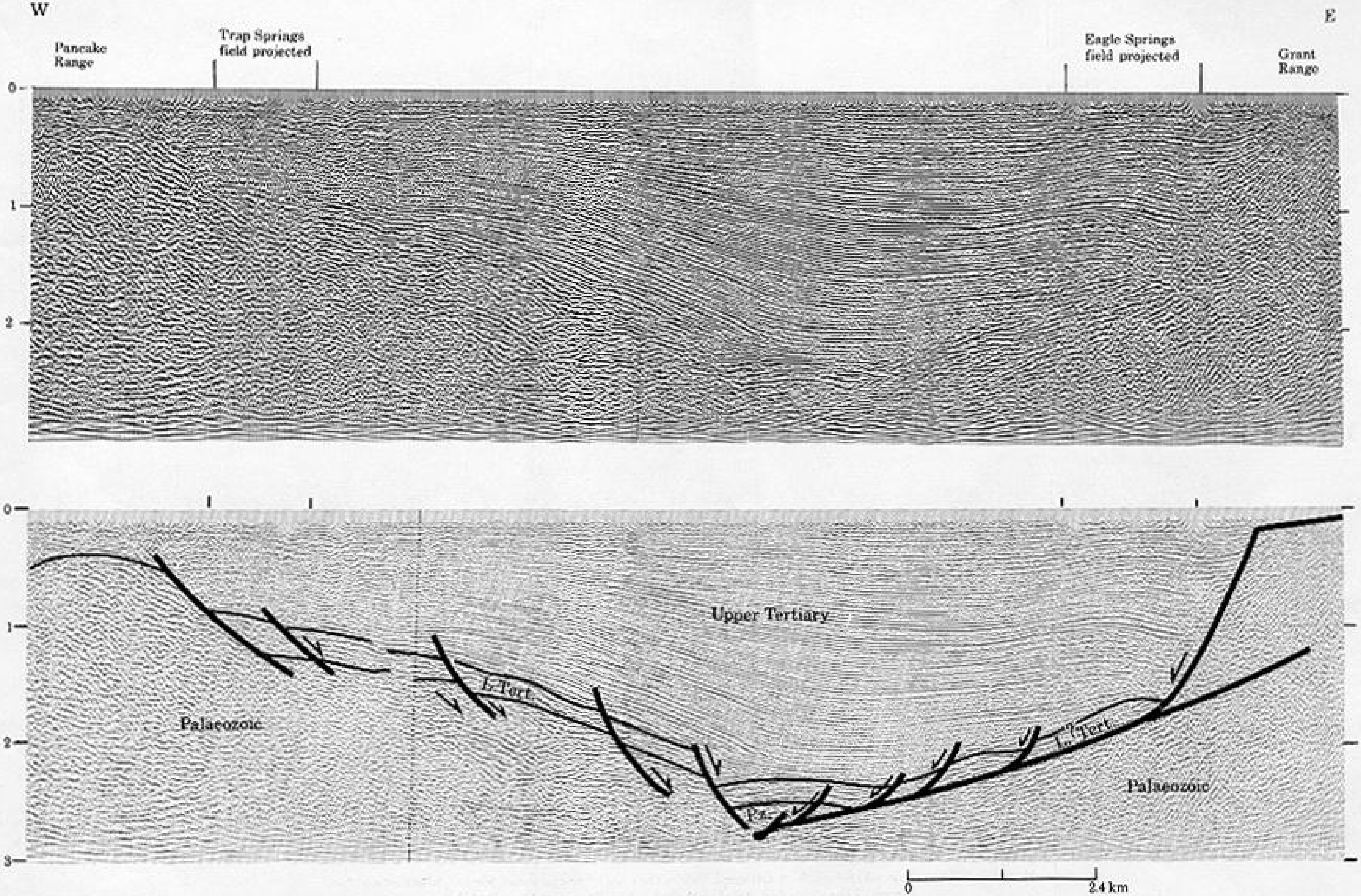

FIGURE 3. Seismic dip profile for Railroad Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 4.5 km.

(*Facing p.* 438)

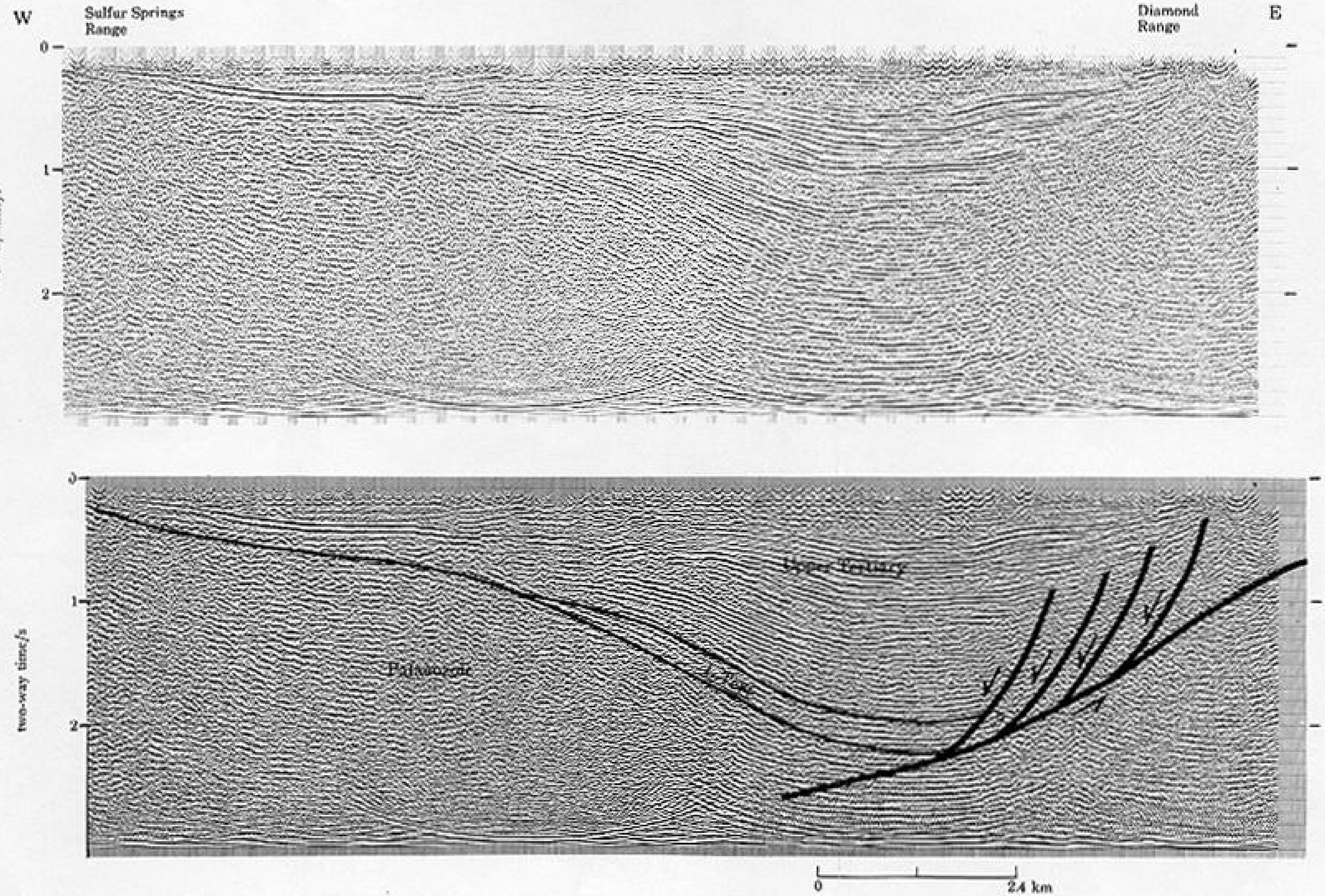

FIGURE 5. Seismic dip profile for northern Diamond Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 3.15 km.

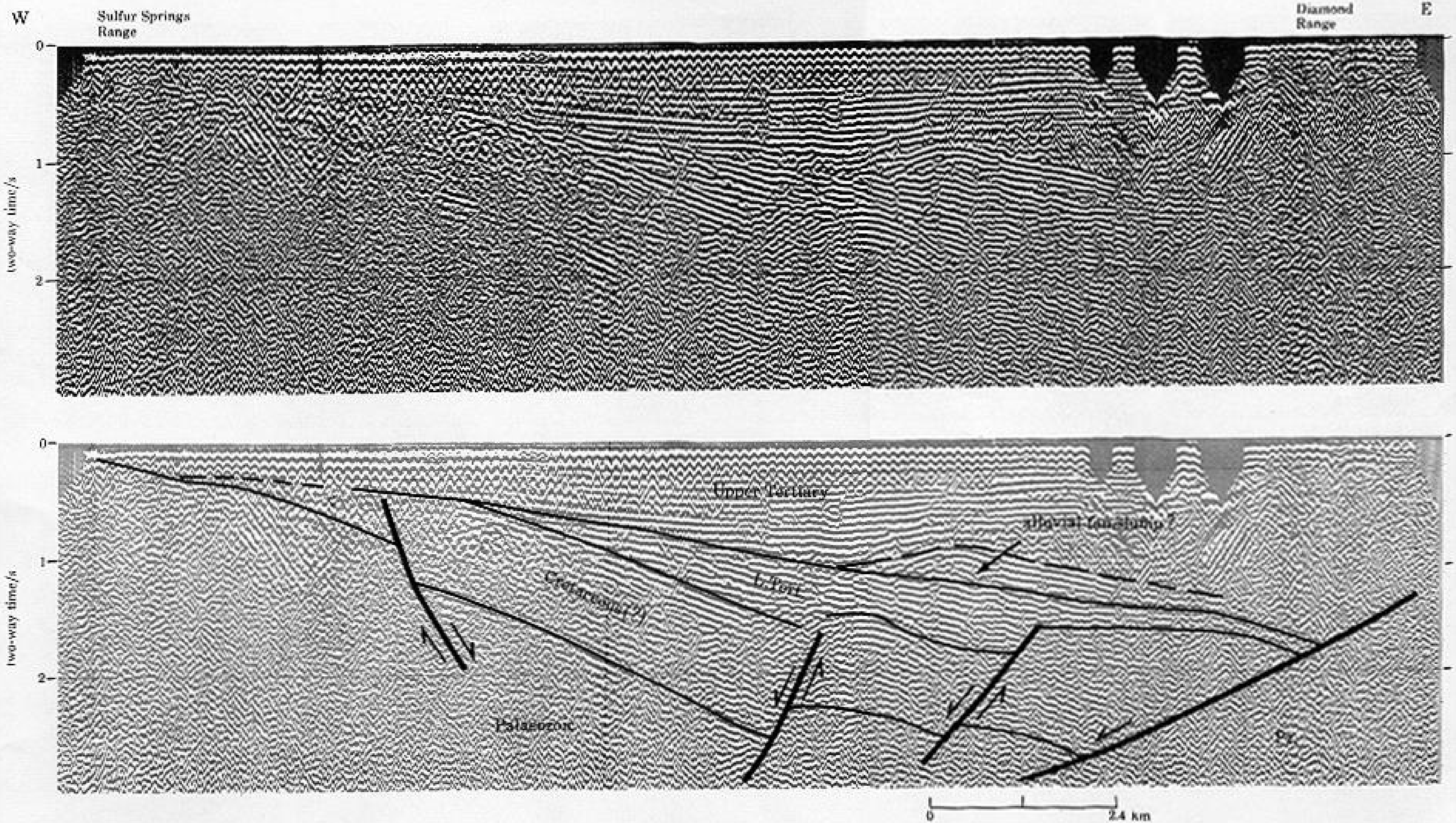

FIGURE 6. Seismic dip profile for southern Diamond Valley. Data are 12-fold coverage, stacked, with automatic statics applied and high frequencies recovered. Maximum thickness of Tertiary and Cretaceous (?) is about 4.5 km.

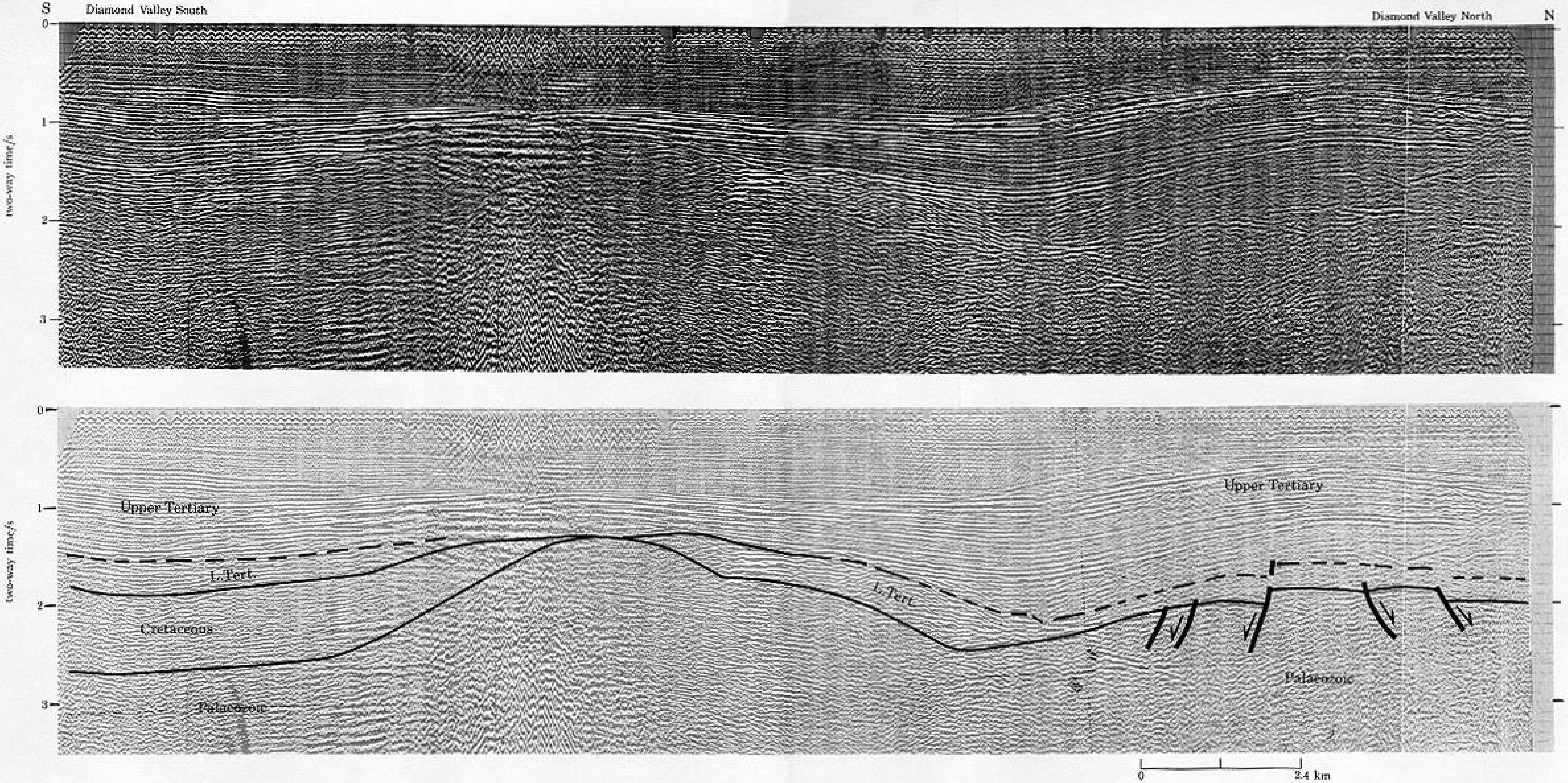

FIGURE 7. Seismic strike profile for Diamond Valley illustrating transverse axis and differences in stratigraphic units in the adjacent basins. Data are 12-fold coverage, stacked and with automatic statics applied.

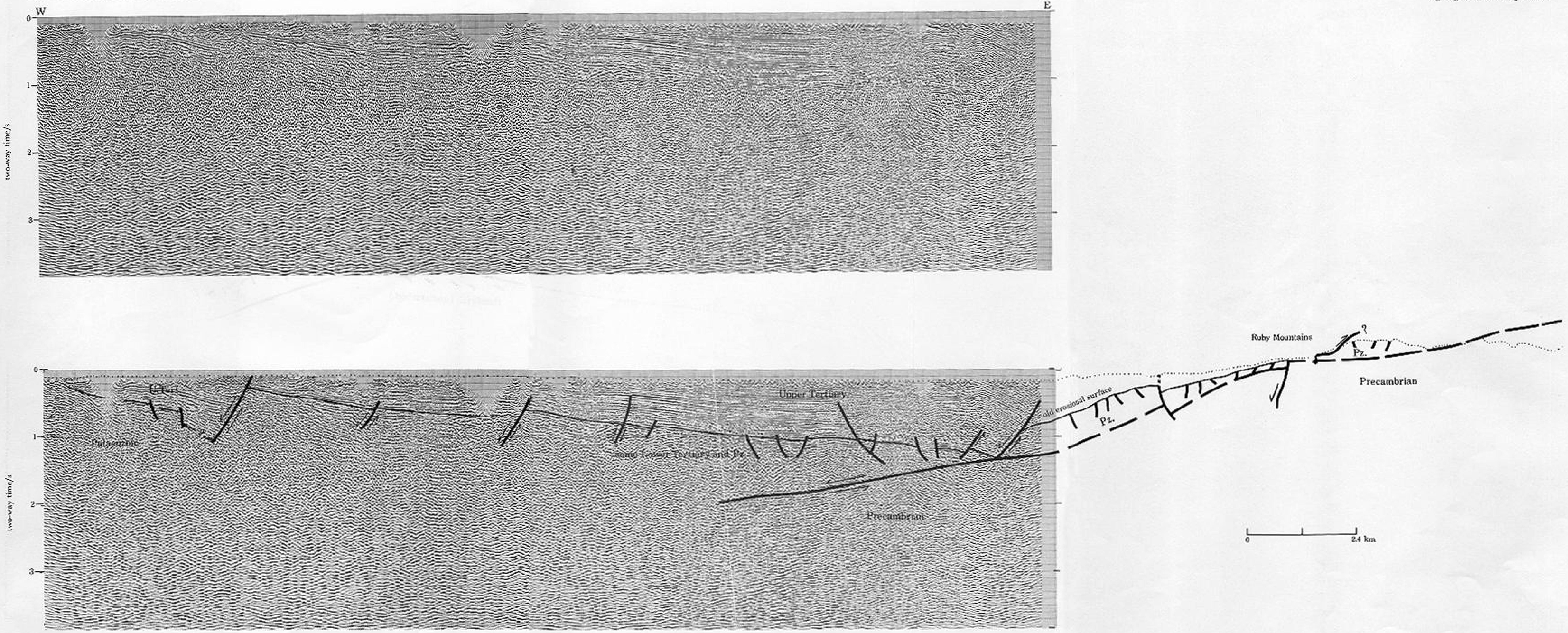

FIGURE 8. Seismic dip profile for Mary's River Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 2.4 km.

(*Facing p. 440*)

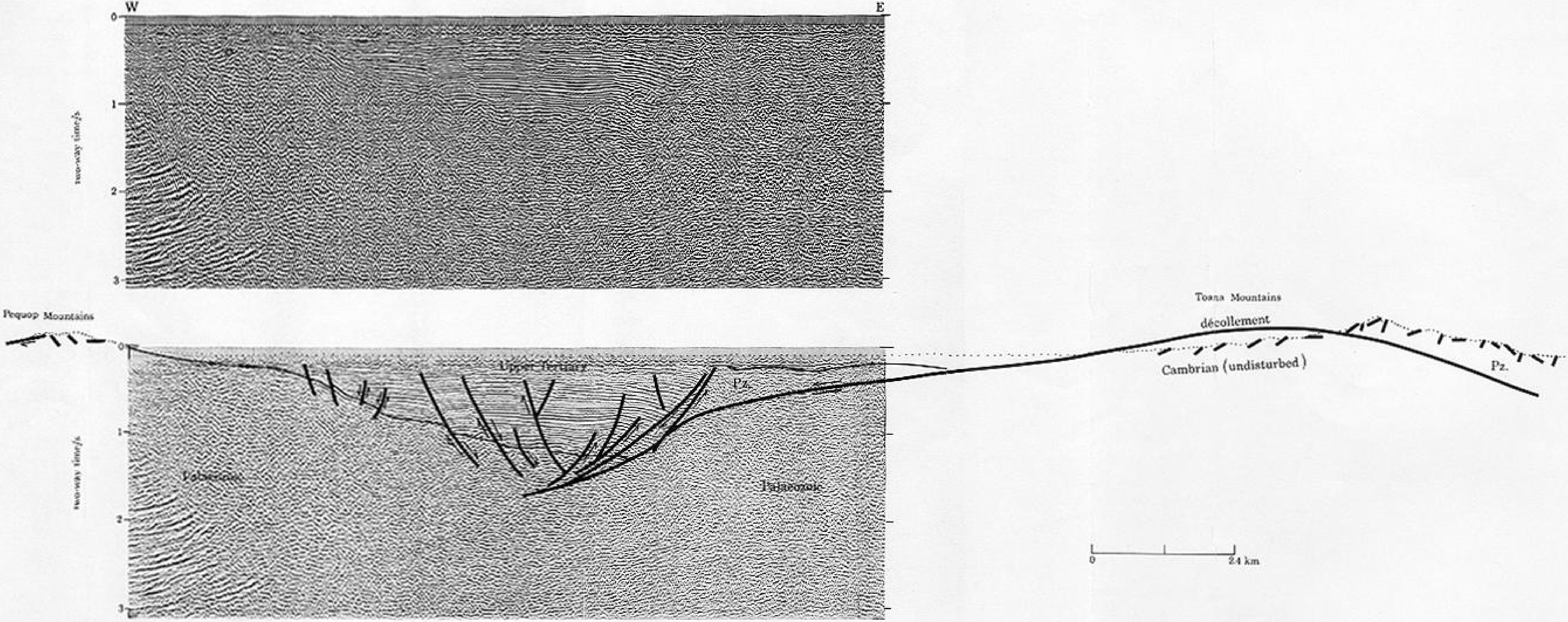

FIGURE 9. Seismic dip profile for Goshute Valley. Data are 12-fold coverage, stacked, migrated and with automatic statics applied. Maximum thickness of Tertiary is about 2.7 km.