Basin Inversion

Most general usage of **inversion** describes a region that has changed from subsidence to uplift, i.e., from **extension** to **compression**

- inversion **may** involve reutilization of original **normal** faults as **reverse or thrust** faults

-reversal of slip introduces concept of **null points** to describe **degree of inversion**

- steep, planar normal are difficult to reactivate, but act as **buttress structures** to shortening

-**Western French Alps** and **intracratonic basins** of NW European Alpine foreland comprise a wide range of **Mesozoic** extensional basins that have been subject the **Cretaceous and Cenozoic inversion** during the development of the **Alpine orogen**

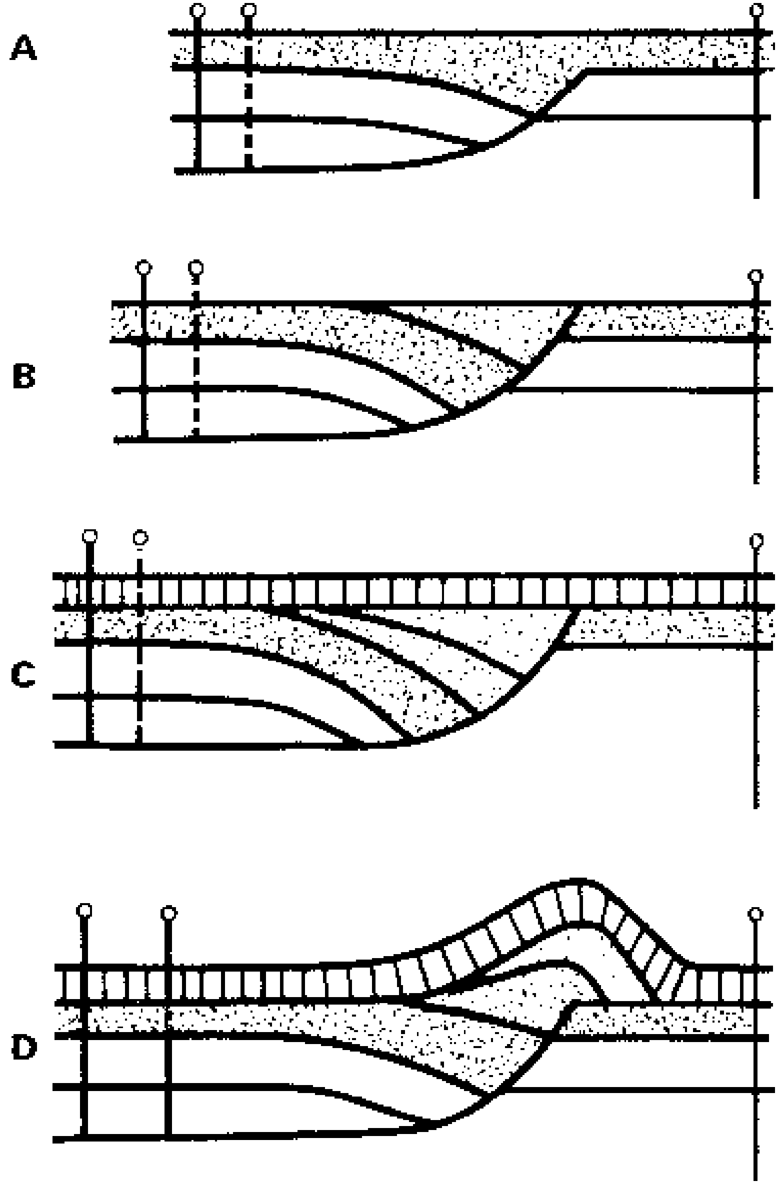


FIG. 1. Graphical construction of a simple listric growth fault subsequently inverted. A, B and C show progressive extension and deposition of a synrift fill (shaded); D shows the subsequent inversion geometry.

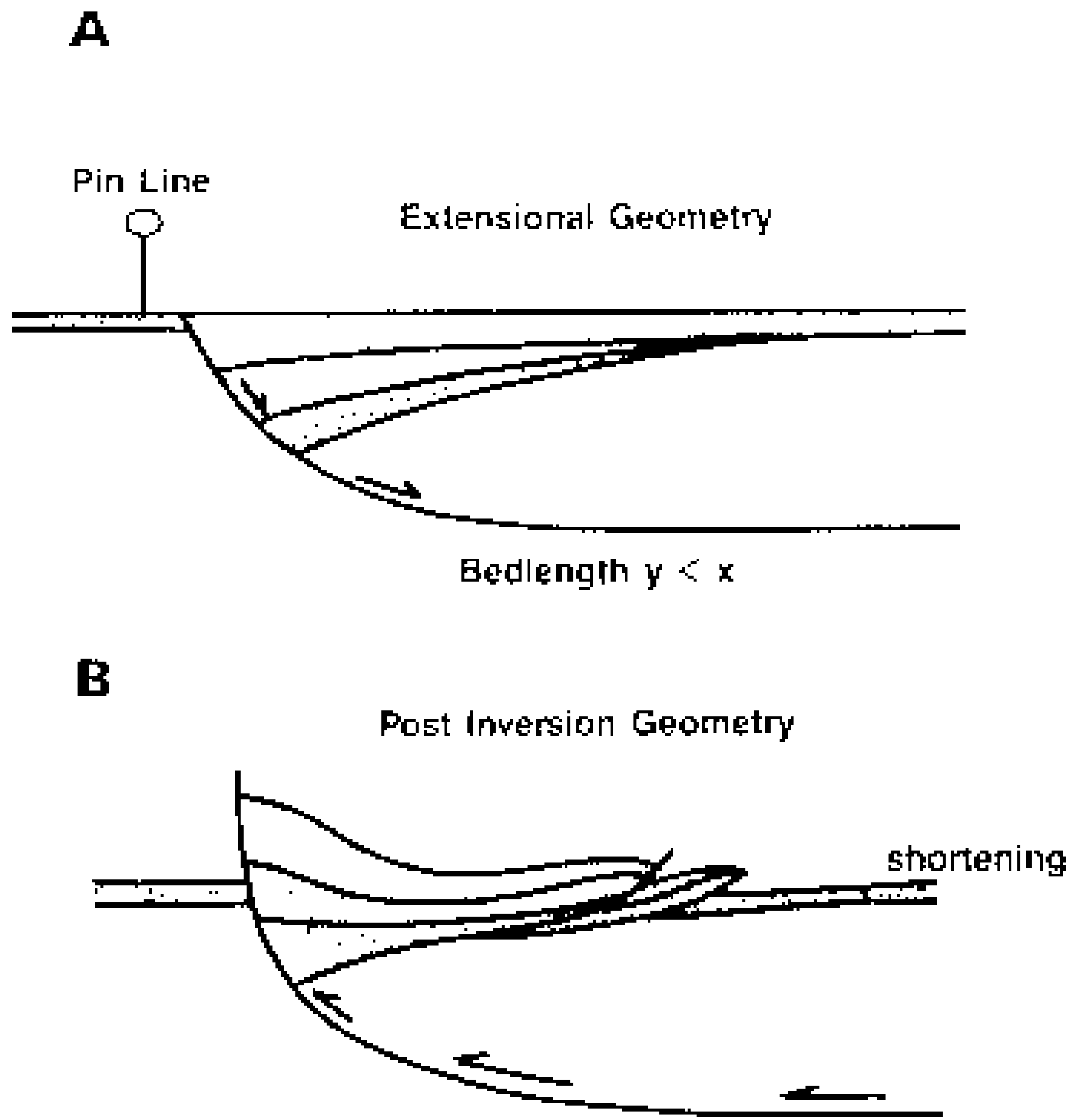


FIG. 2. A, The excessive bed length in the cover sequence to an asymmetric half-graben and B, the accommodation structures that develop during inversion of the half-graben (in part after Bally 1984).

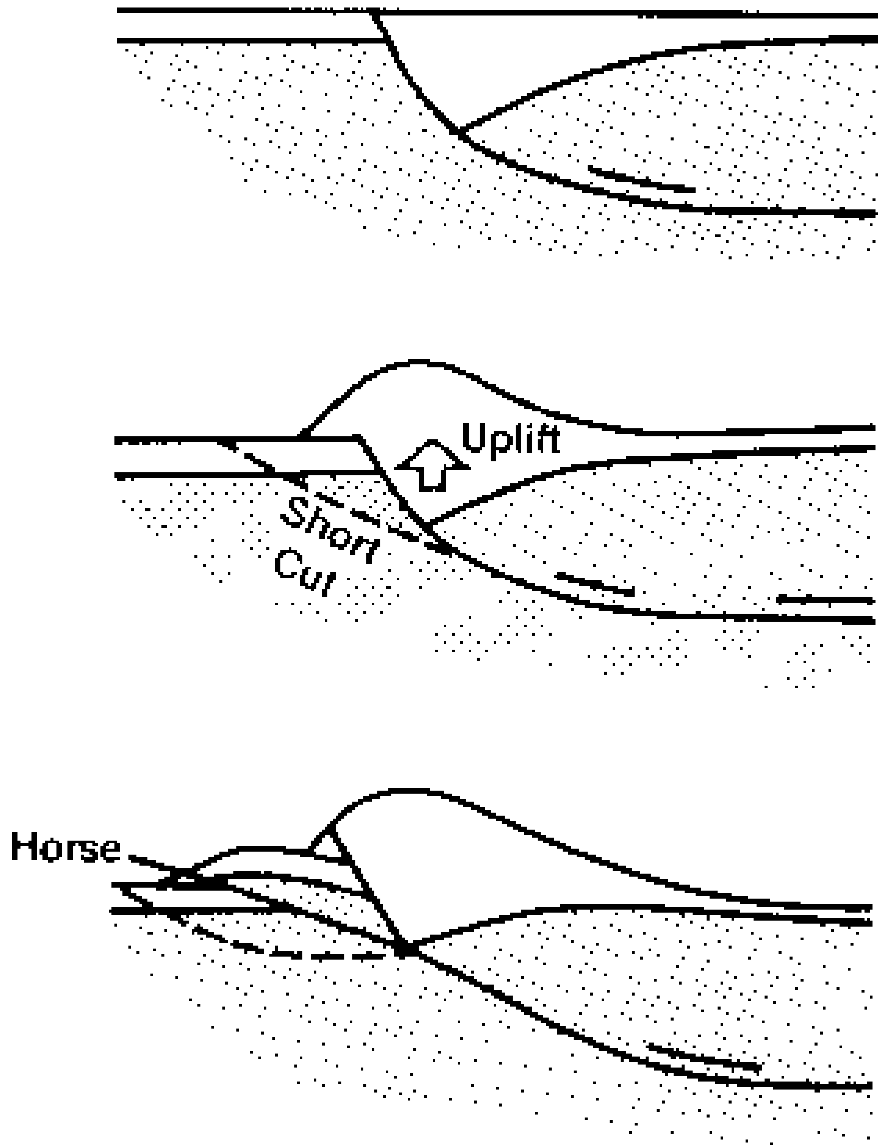


FIG. 19. Model for the development of a footwall shortcut thrust system.

Strong inversion of the northern Tethyan margin in the western French Alps

Tethys was the Mesozoic ocean that existed between Europ and Africa

- main **extensional** phases in the **Lower Jurassic** produced a complex pre-compressional extensional **template**
- field evidence is both **stratigraphic** (basin fill stratigraphy) and **structural** (preservation of Lower Jurassic age extensional structures)
- inversion of the northern Tethyan margin began in the **late Cretaceous**, with **main Alpine phase** in the **Oligo-Miocene** (250 km of shortening)
- **thrusting and folding** of extensional template was complex; **buttressing, footwall shortcuts, out of sequence thrusting etc.**

Moderate/Weak inversion of the Celtic Sea basins of western Britain

Celtic Sea basins were part of a major intracratonic **failed rift** system during the Triassic and Jurassic. Thick sequence of sediments (up to 10 km) deposited in **NE-SW** trending (Caledonian) **rift basins**

- rift basins were **compartmentalized** by NW-SE trending tear faults
- inversion in the Celtic Sea basins began in the **Early Cretaceous**, with other major phases dated at **Paleocene and Oligo-Miocene**
- inversion geometries are mainly in the form of **broad folds**, with minor thrusting and some fault reactivation
- **correlation** between Alpine events and inversion in western Britain is not clear cut; localized **uplift** and influence of **spreading in the North Atlantic** were also important

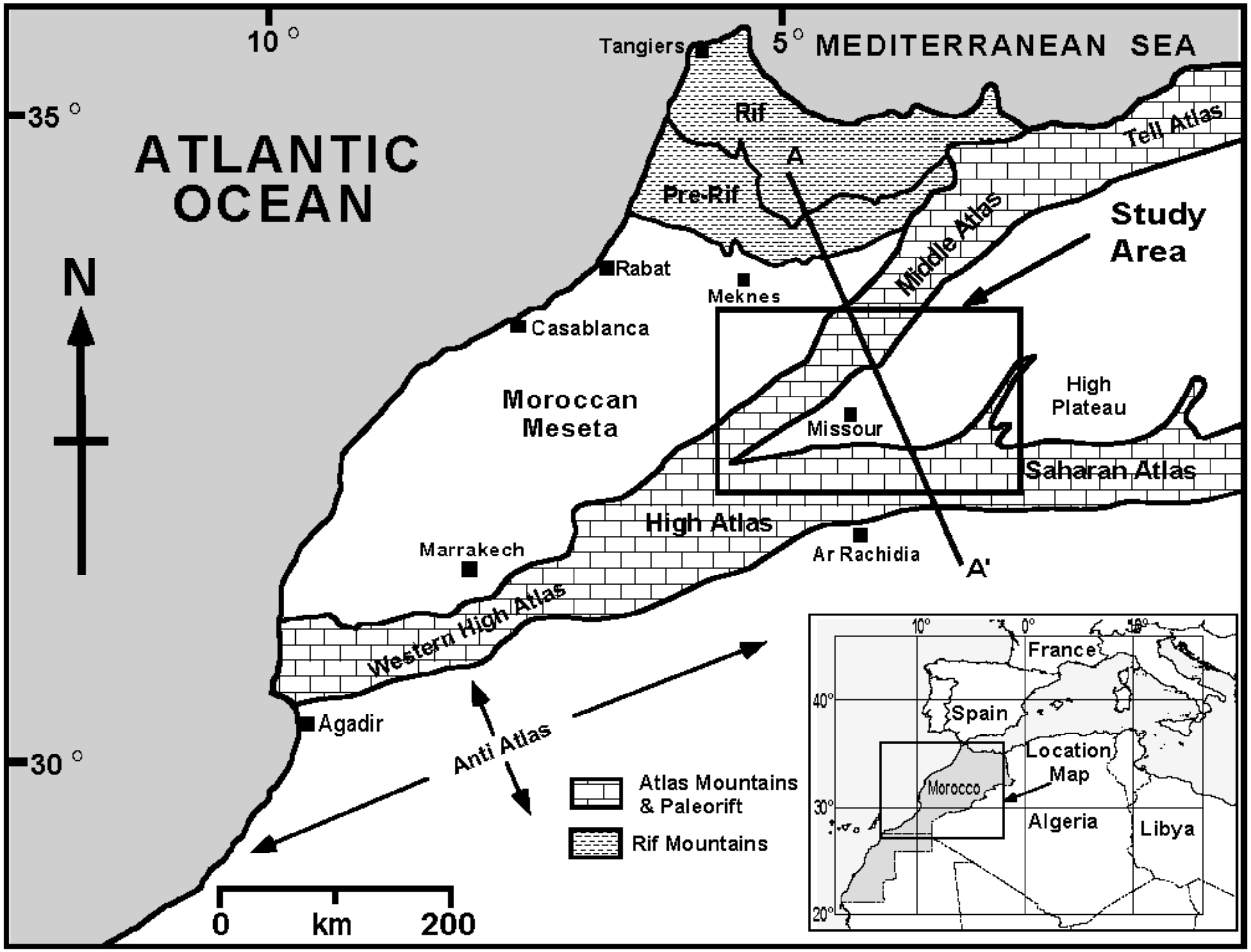


Figure 1—Location map of the Atlas mountains and Missour basin of Morocco. The Missour basin is bounded by the Middle Atlas and High Atlas mountains.

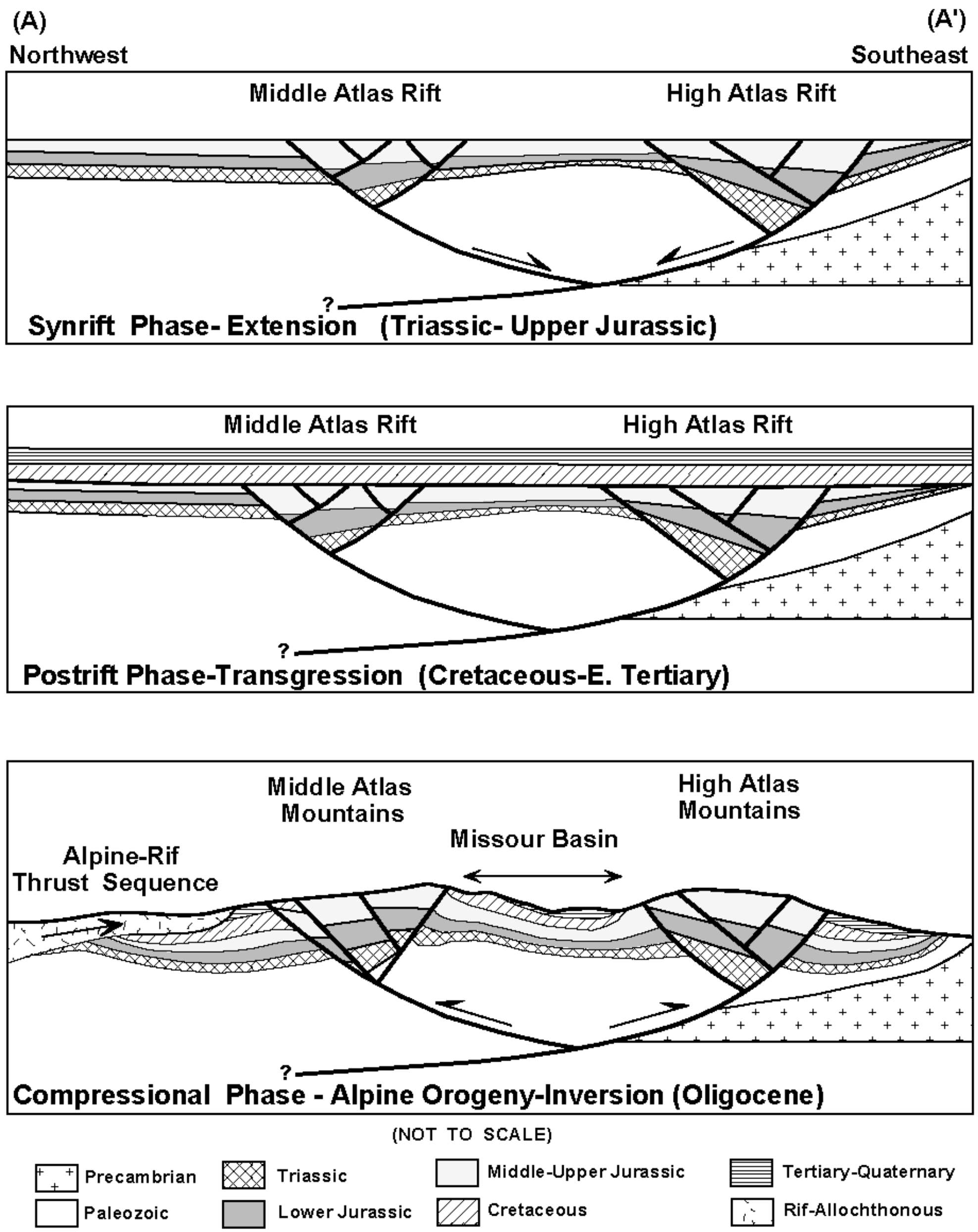


Figure 2—Conceptual model for the development of the Missour basin and the Atlas Mountains, Morocco. See Figure 1 for location of AA′.

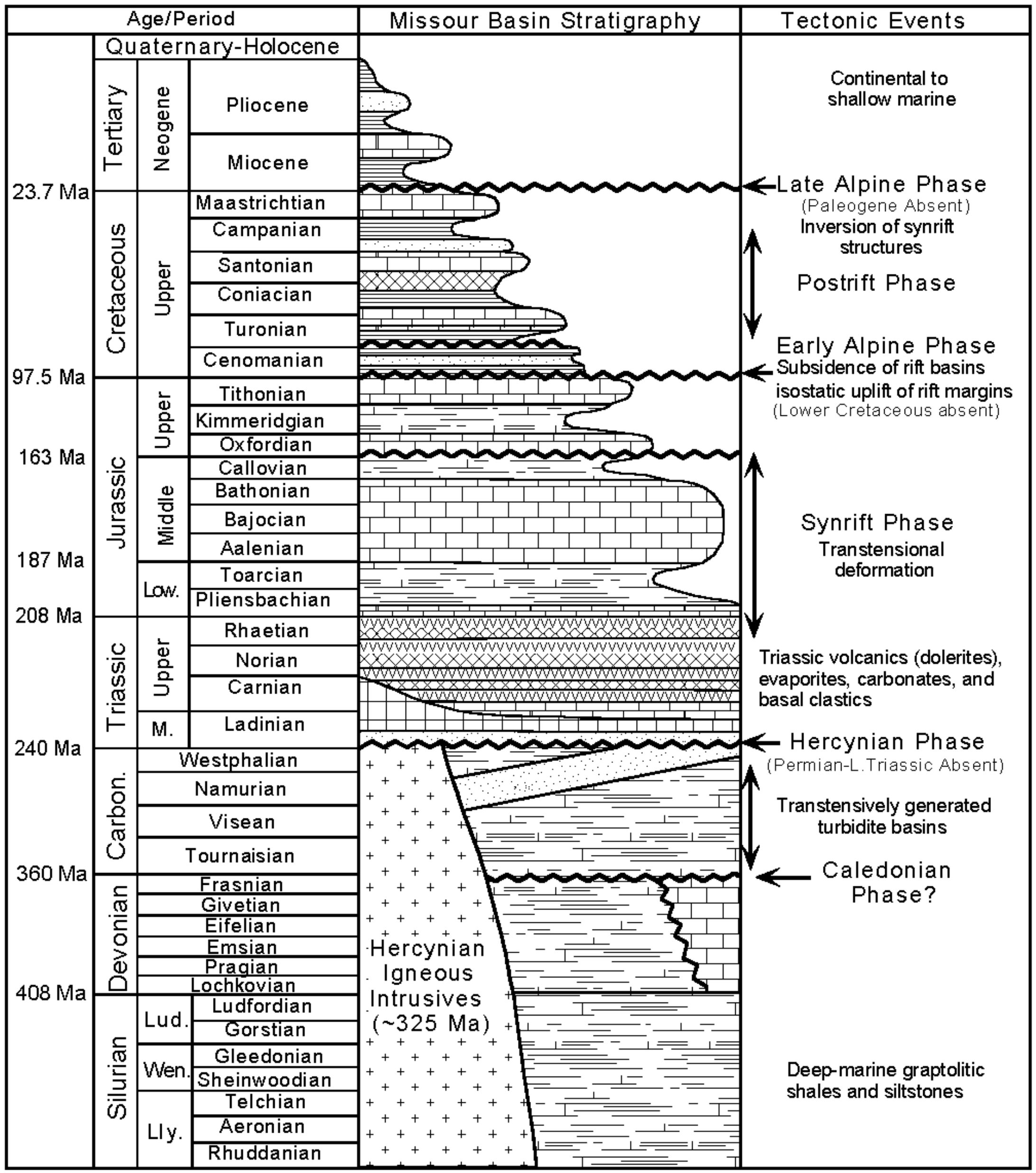


Figure 4—Stratigraphy of the Missour basin based on well penetrations (OSD-1, RR-1, KSAB-101, KSAB-102, and TT-1; see Figures 5 and 12, and Table 1), seismic stratigraphy, and outcrops within the basin. Several phases of deformation are related to major unconformities in the basin.

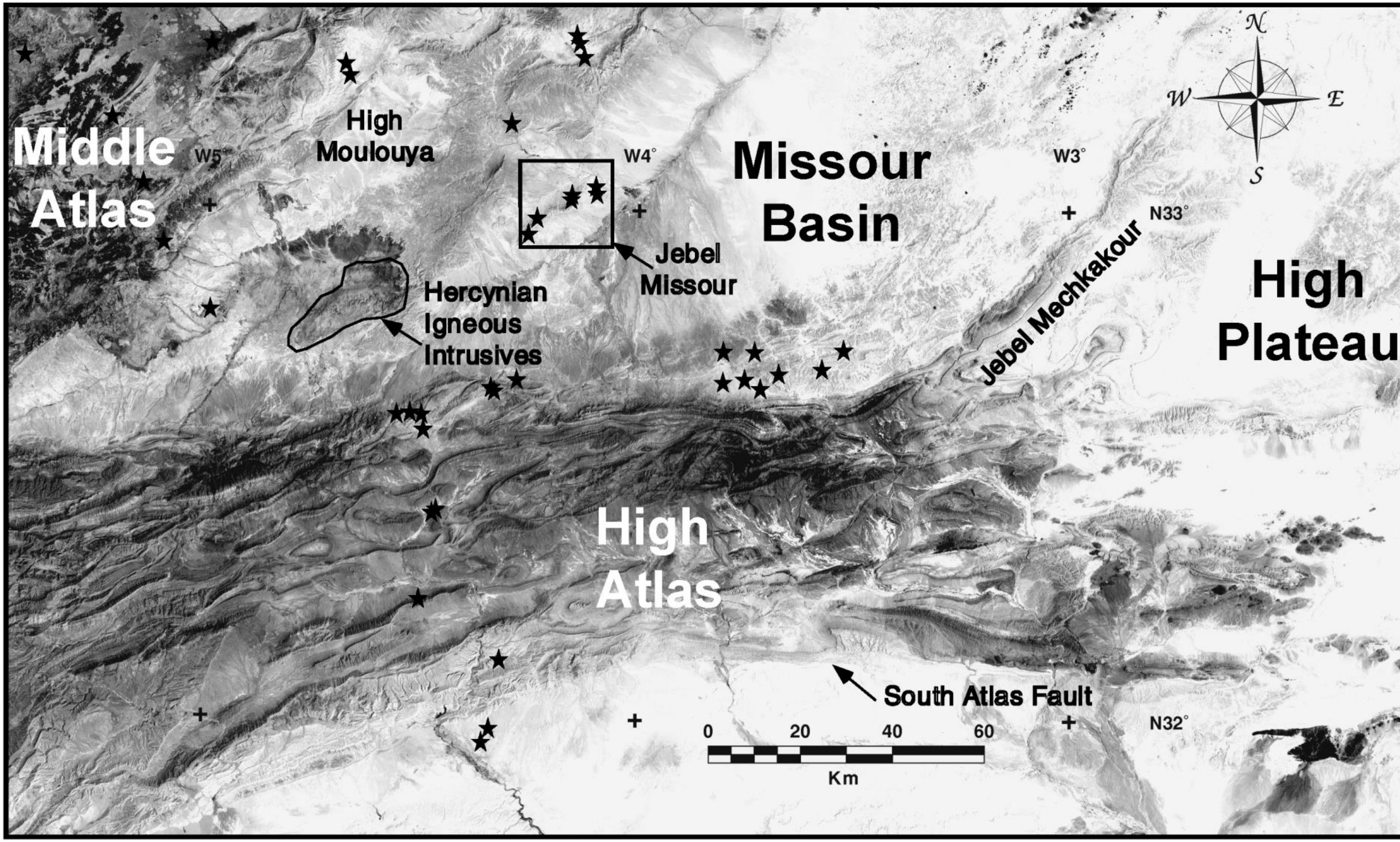


Figure 6—LANDSAT TM (band 5, infrared) mosaic of the Missour basin and parts of the High Atlas and the Middle Atlas mountains. Field locations where structural data were collected are shown as stars. The eastern margin of the Missour basin is bounded by the northeast-trending Jebel Mechkakour. The location of Jebel Missour is shown to the east of the High Moulouya. The structures seen in the High Atlas Mountains show polyphase deformation.

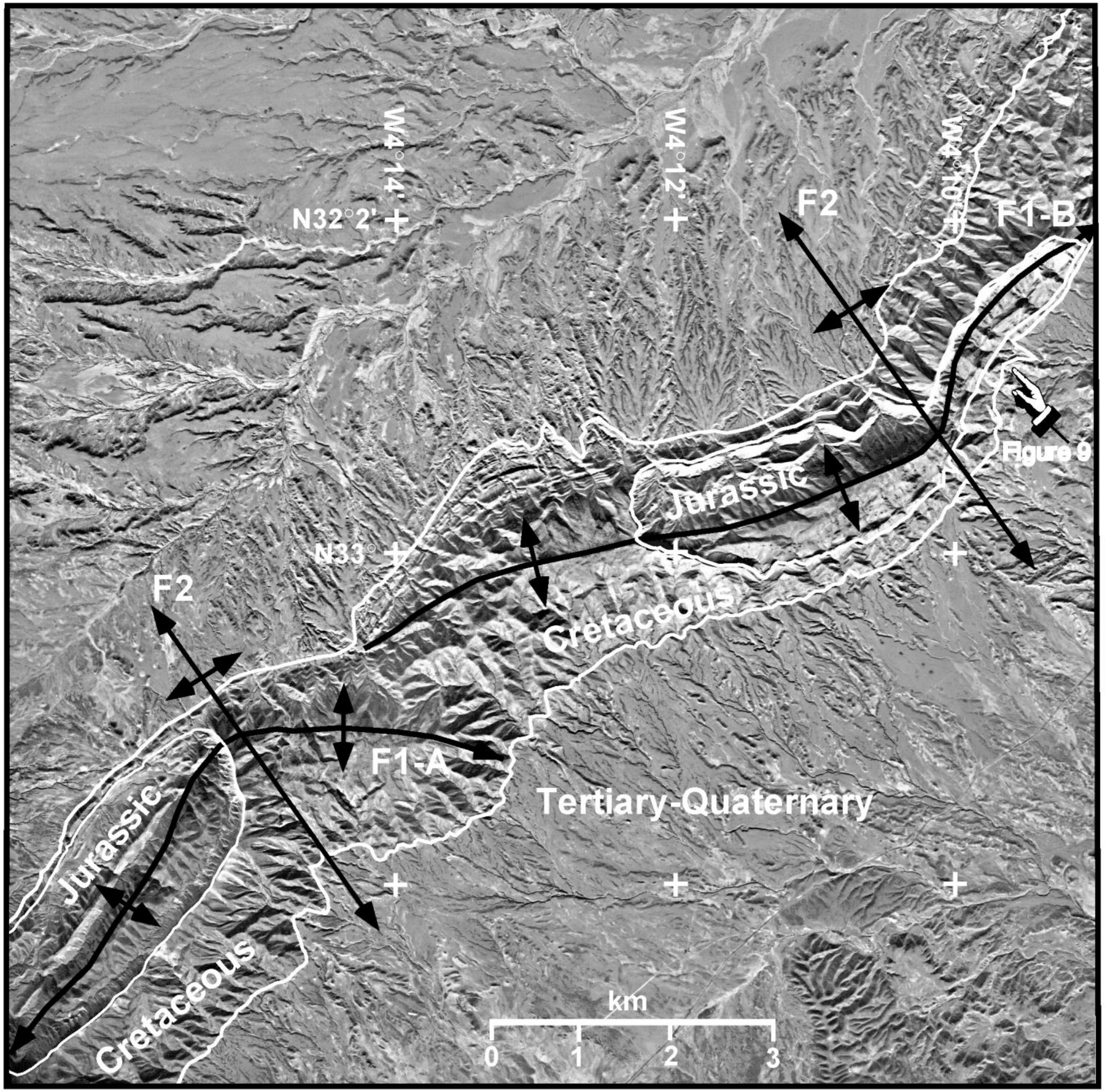


Figure 7—Aerial photograph of the Jebel Missour region (located on Figure 6). Two northeast-trending anticlinal structures show two phases of deformation (F1 and F2). Fold F1-A and F1-B are verging in opposite directions. Jurassic synrift sedimentary rocks are exposed in the core of both anticlines separated by the base Cretaceous unconformity. The Tertiary and Quaternary sedimentary rocks are flat lying and onlap the two structures. Location of Figure 9 is shown near F1-B.

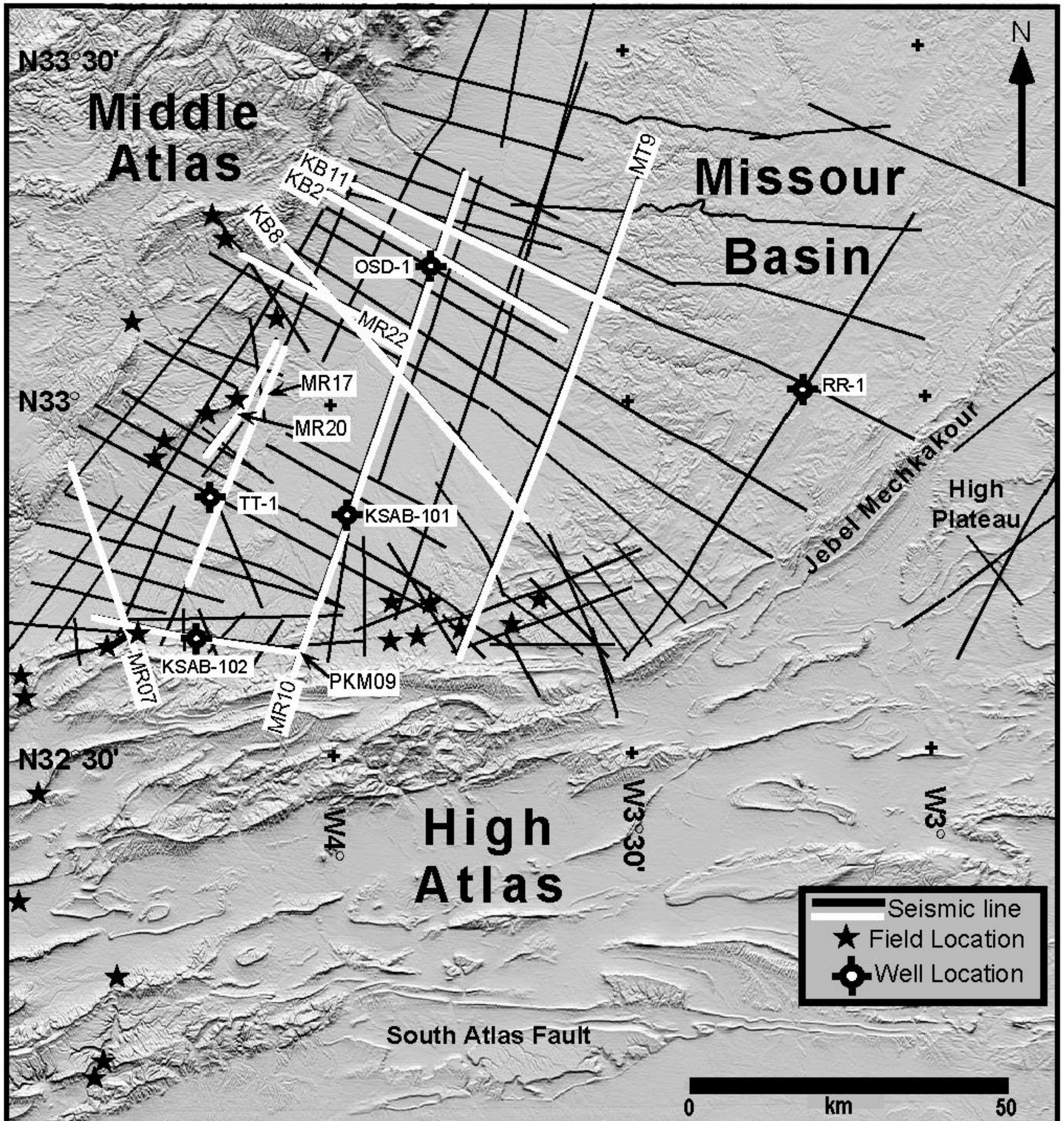


Figure 12—Map showing digital topography of the Missour basin and the adjacent High and Middle Atlas mountains; seismic reflection profiles, well data, and field locations are shown. A total of 3400 km of seismic lines were used to study the tectonic evolution of the Missour basin and Atlas Mountains. The seismic lines in white are those used in this paper; both black and white lines were used in the study.

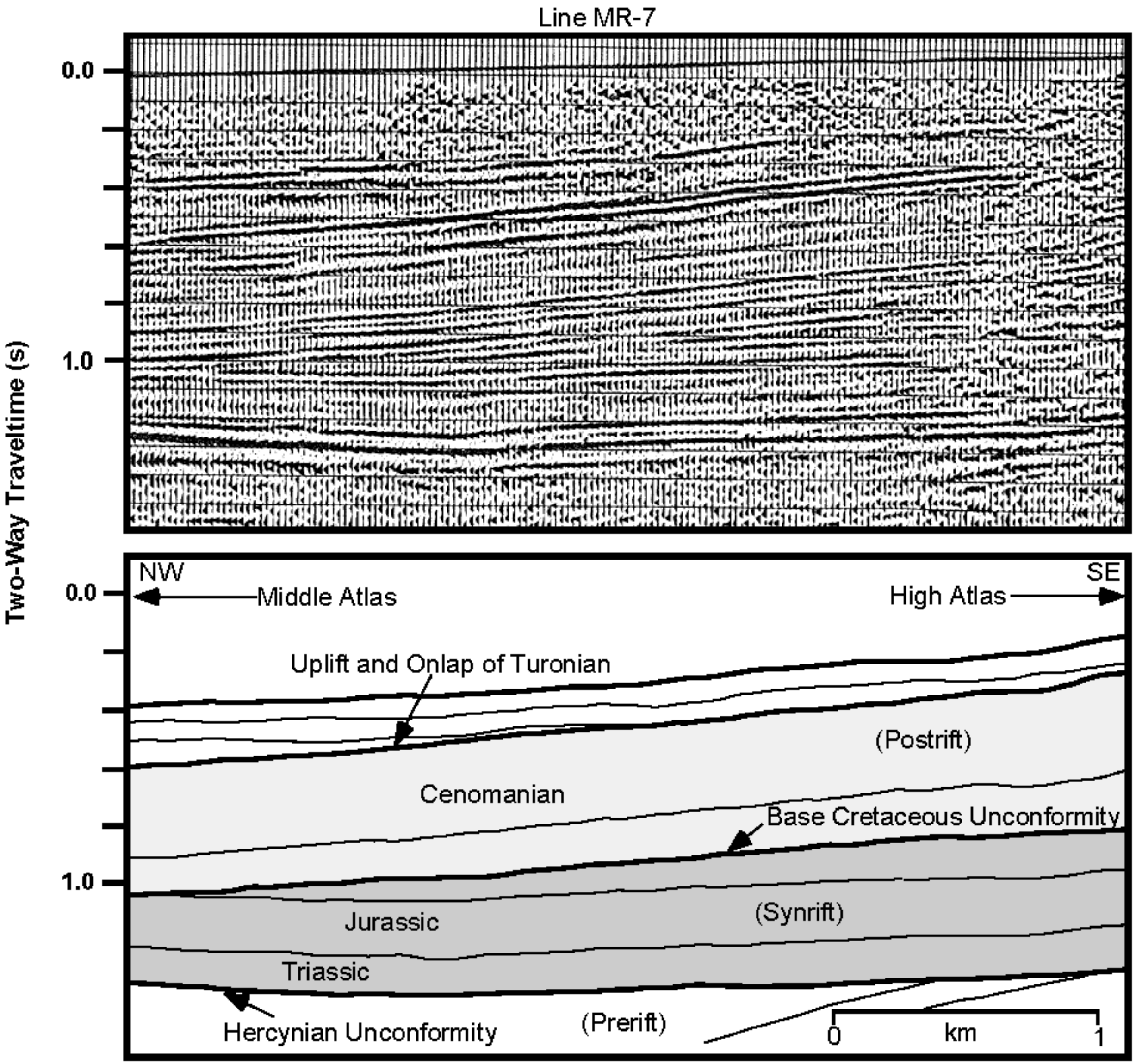


Figure 13—Major unconformities that illustrate tectonic phases (Hercynian, base Cretaceous, and Turonian?) are seen on seismic line MR-7. The Hercynian unconformity has been "flattened" by the inversion of the stratigraphic section. The synrift and postrift sections have been rotated upwards reversing the original sense of regional dip (location on Figures 12, 17).

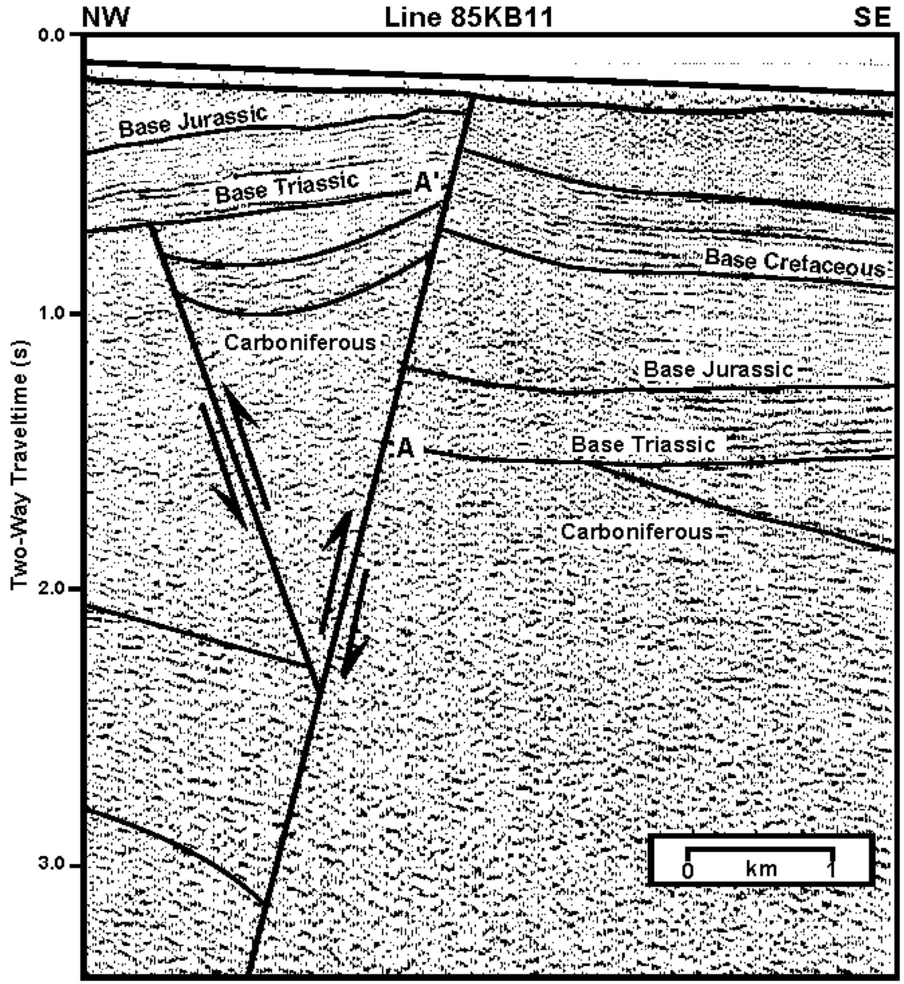


Figure 14—Seismic profile 85KB11 located near the southeast margin of the Middle Atlas Mountains (location on Figure 12). The null point is the point at which AA′ is adjacent across the fault. Note the uplift of the Triassic unconformity. Erosion by the base Cretaceous unconformity has removed any indication of whether the fault was a reactivated synrift fault or a newly formed reverse fault.

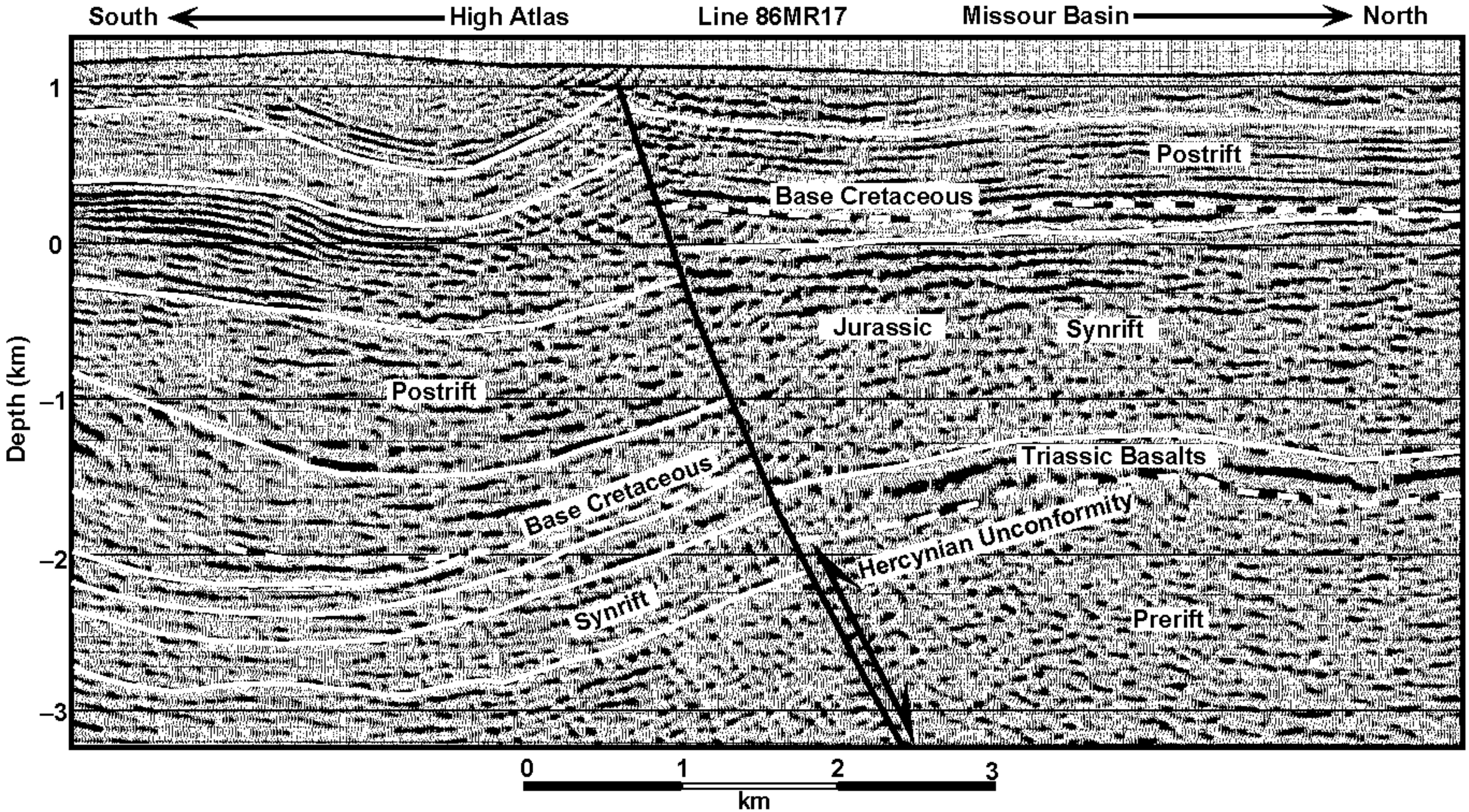


Figure 15—Seismic profile 86MR17 shows the uplift of the Hercynian unconformity above the null point. There has been an apparent uplift of 2 km on the Hercynian unconformity. The amount of shortening normal to the fault is limited due to the geometry of the fault, and subsequent strain is accommodated by strike-slip or oblique-slip movement (location on Figure 12).

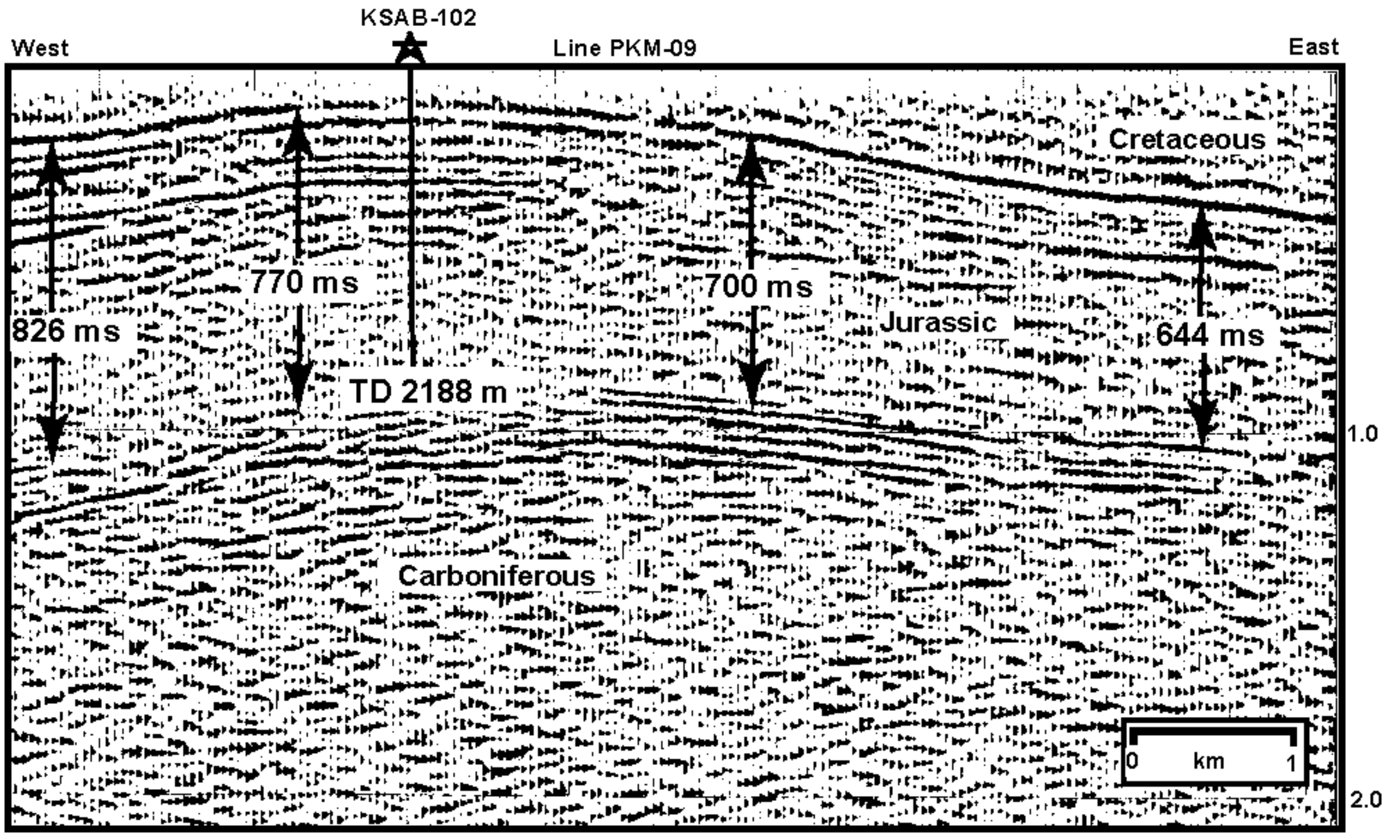


Figure 16—Seismic profile PKM-09. Inversion can be demonstrated by the uplift of a previous half graben. Thickening from the right to left across the section can be seen from a reflector in the synrift sequence to a reflector at the top of the Triassic basalts (location on Figure 12).

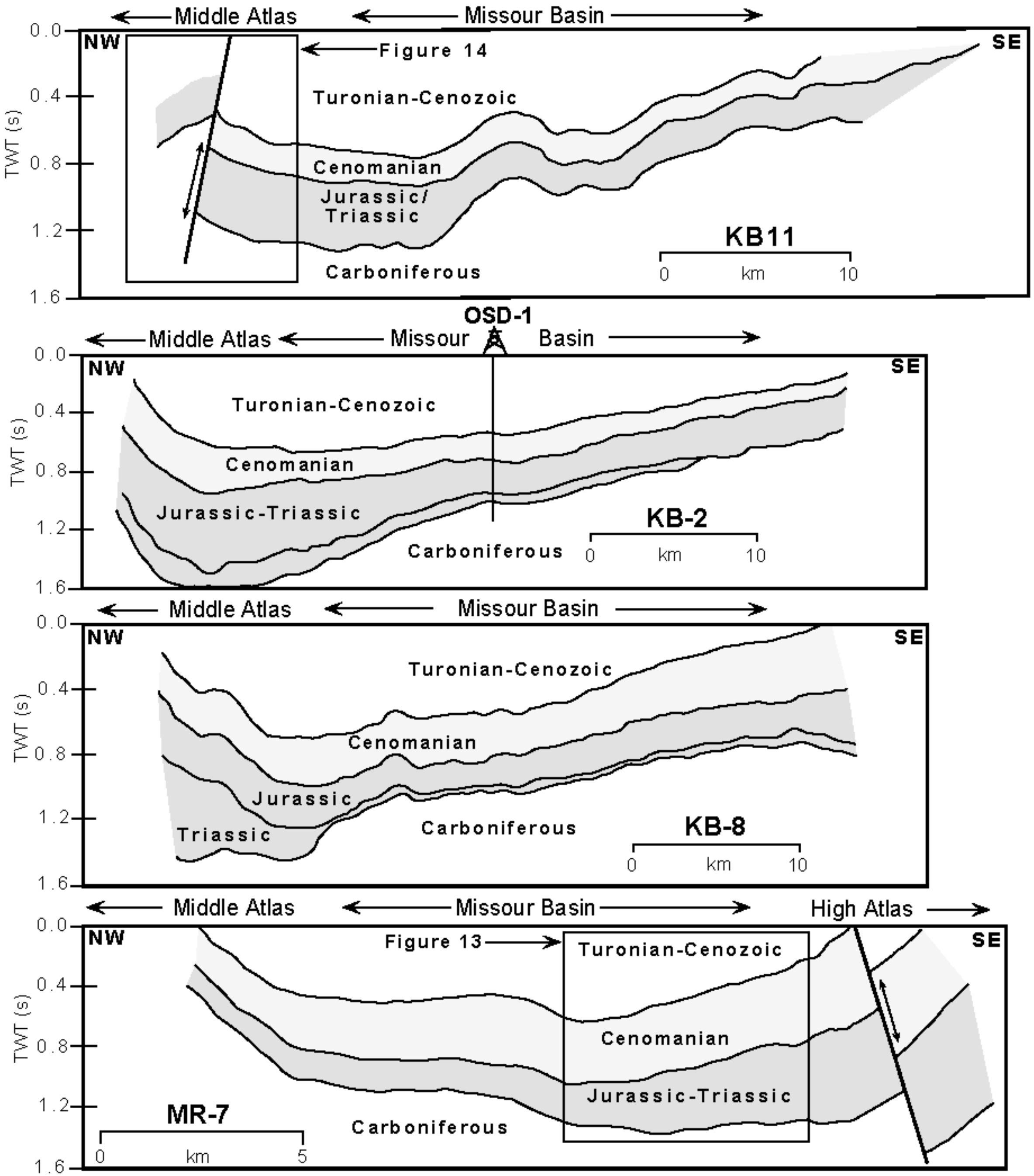


Figure 17—Interpretations of regional seismic profiles across the Missour basin. Note the thickening of the synrift sequences (Triassic–Jurassic) out of the Missour basin into the paleo-Atlas rifts (Middle and High Atlas mountains). Regional inversion effects can be seen by the uplift of the stratigraphic section near the basin margins. The base Cretaceous unconformity in some cases may have removed the sense of synrift thickening into the rift (KB-2). The locations of Figures 13 and 14 are shown. TWT = two-way traveltime.

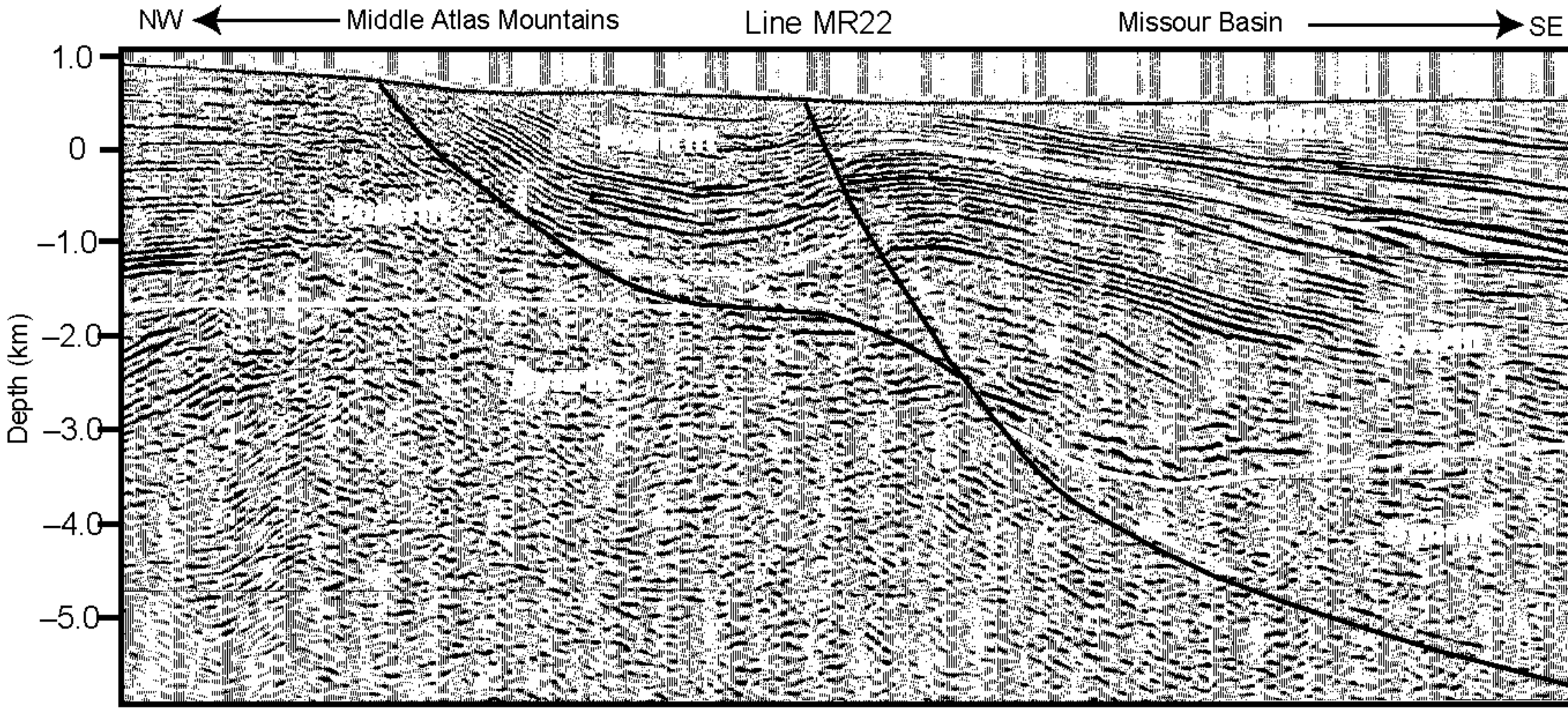


Figure 18—Seismic line MR22 was migrated and depth converted to enable the modeling of the reactivated listric normal fault seen on the seismic profile. Thickening of the synrift sedimentary rocks is evident from the southeast to the northwest into a listric normal fault that dips to the southeast.

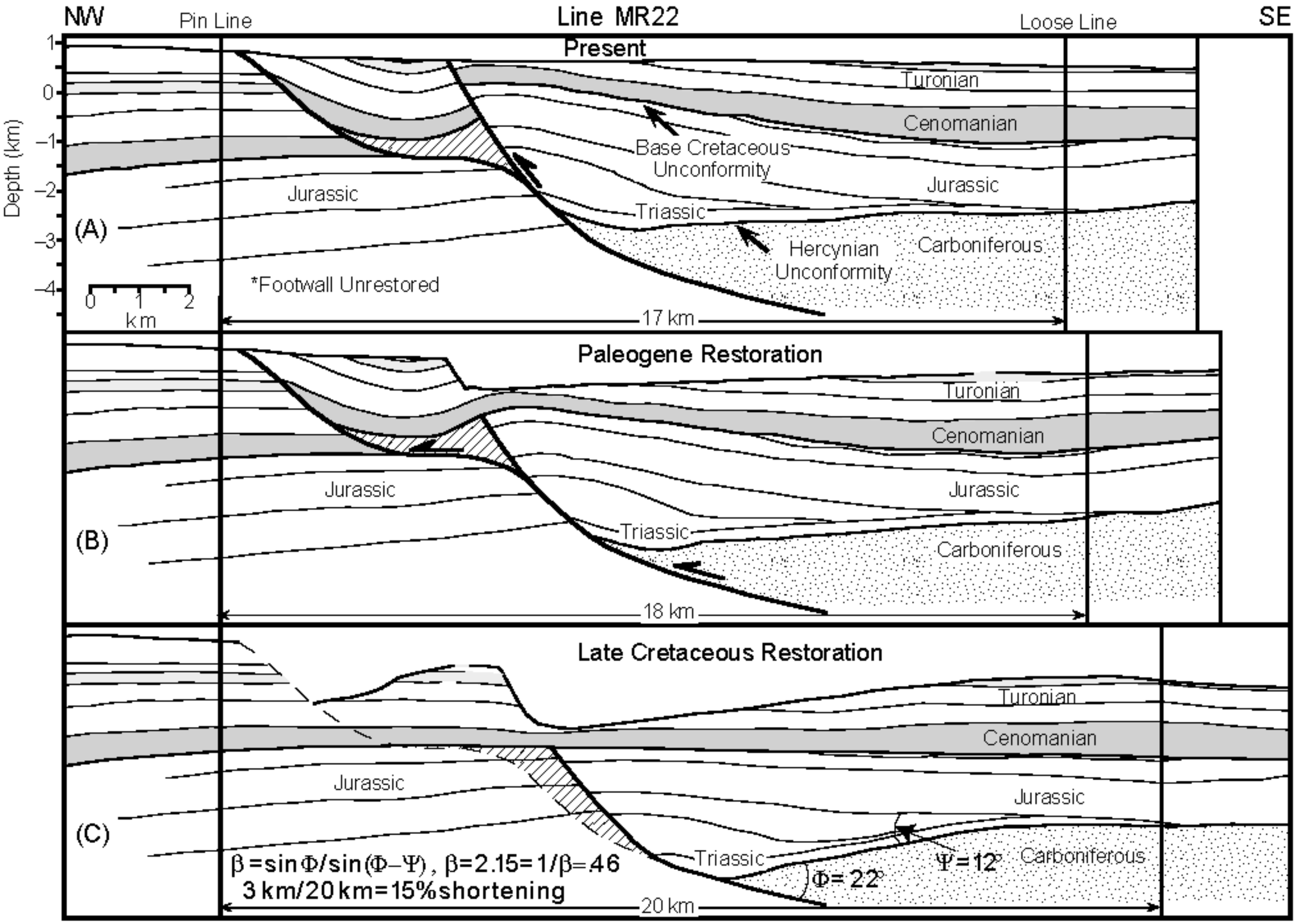


Figure 19—Restoration of migrated and depth converted seismic reflection line MR22. Reactivation of the synrift listric fault occurs until the fault steepens, and the synrift fault is bypassed. Shortening is then accommodated by a thrust that cuts the footwall at a lower angle (C). A fault-bend fold forms over the new footwall ramp (B), and is later faulted along the forelimb by the reactivation of the original synrift normal fault (A). Shortening then occurs in the hanging wall along the high-angle reverse fault. Shortening of the original half graben is approximately 15%. The thinning factor β is approximately 0.46 that is the inverse of McKenzie's (1978) stretching factor β.

YY&KM
Figs.1-3

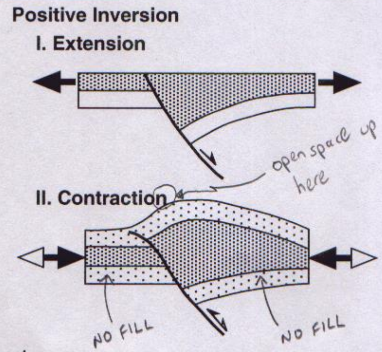


Fig. 1

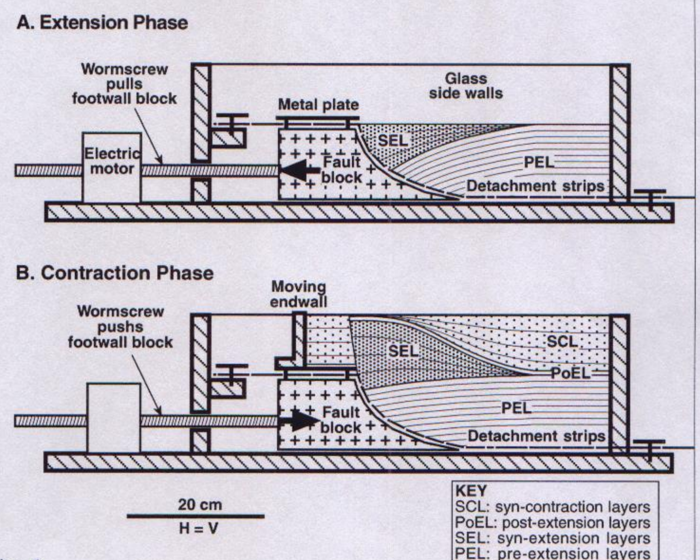


Fig. 2

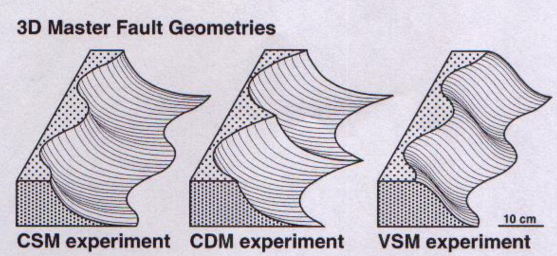
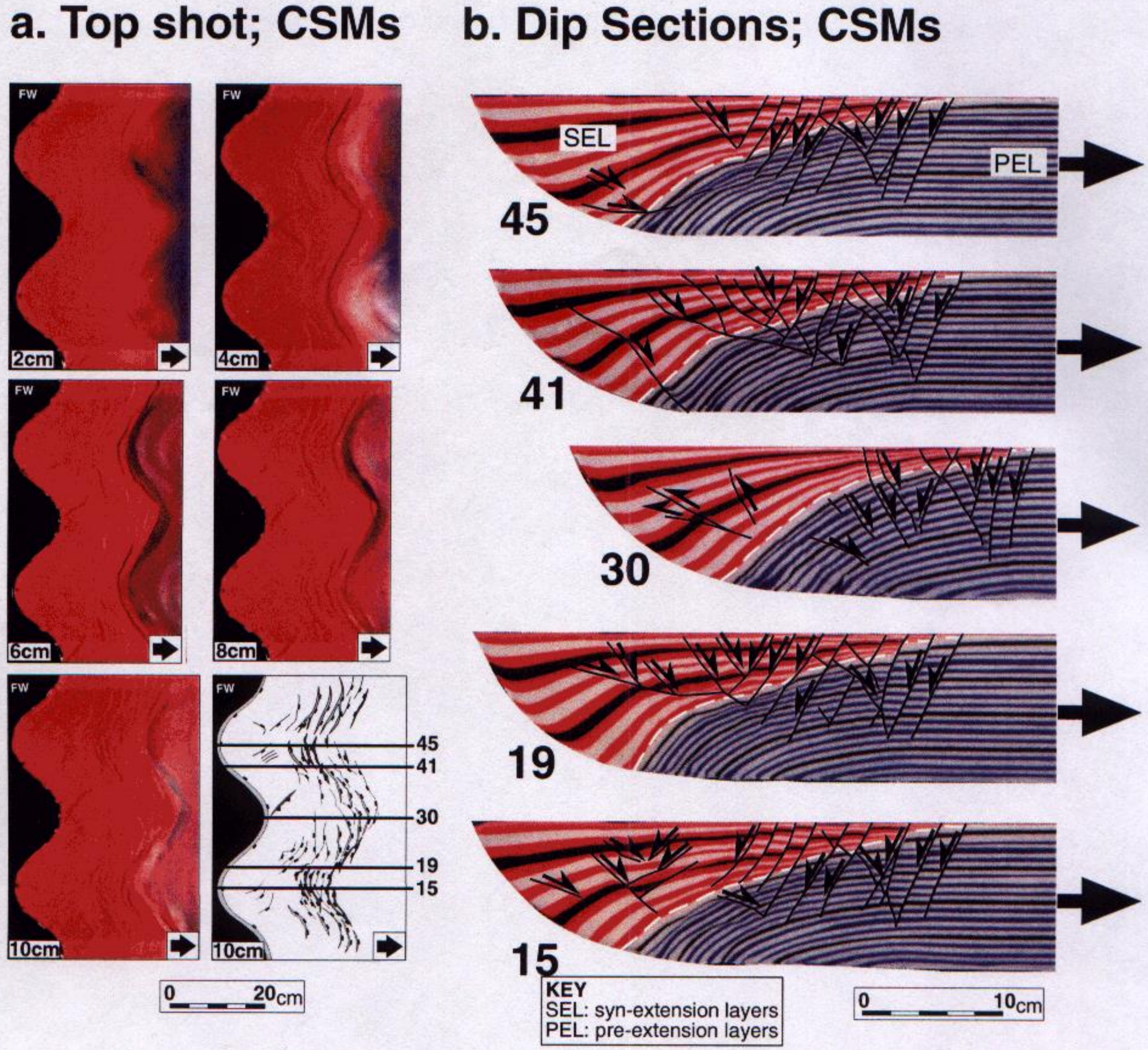


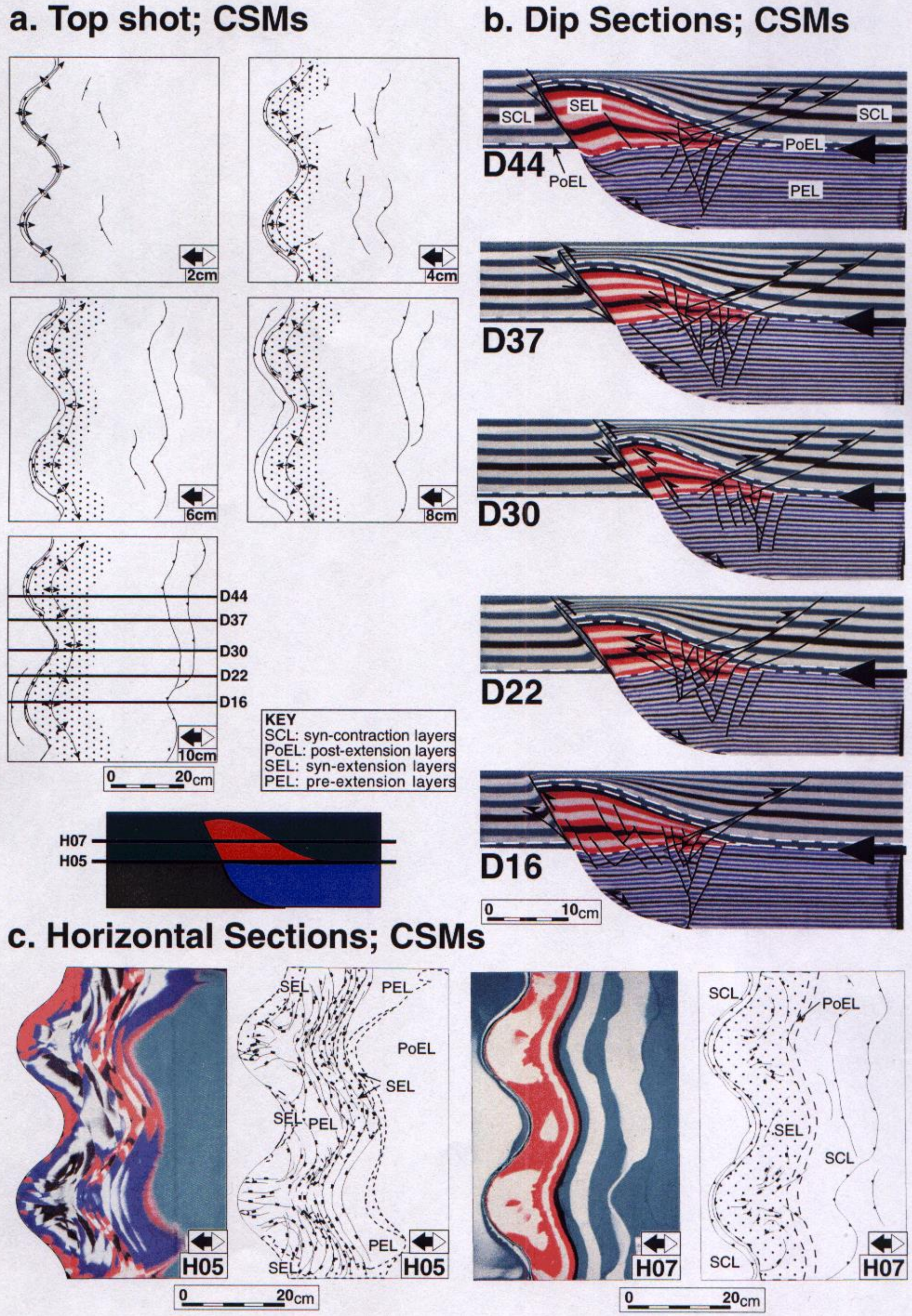
Fig. 3

YY&KM
Fig.4



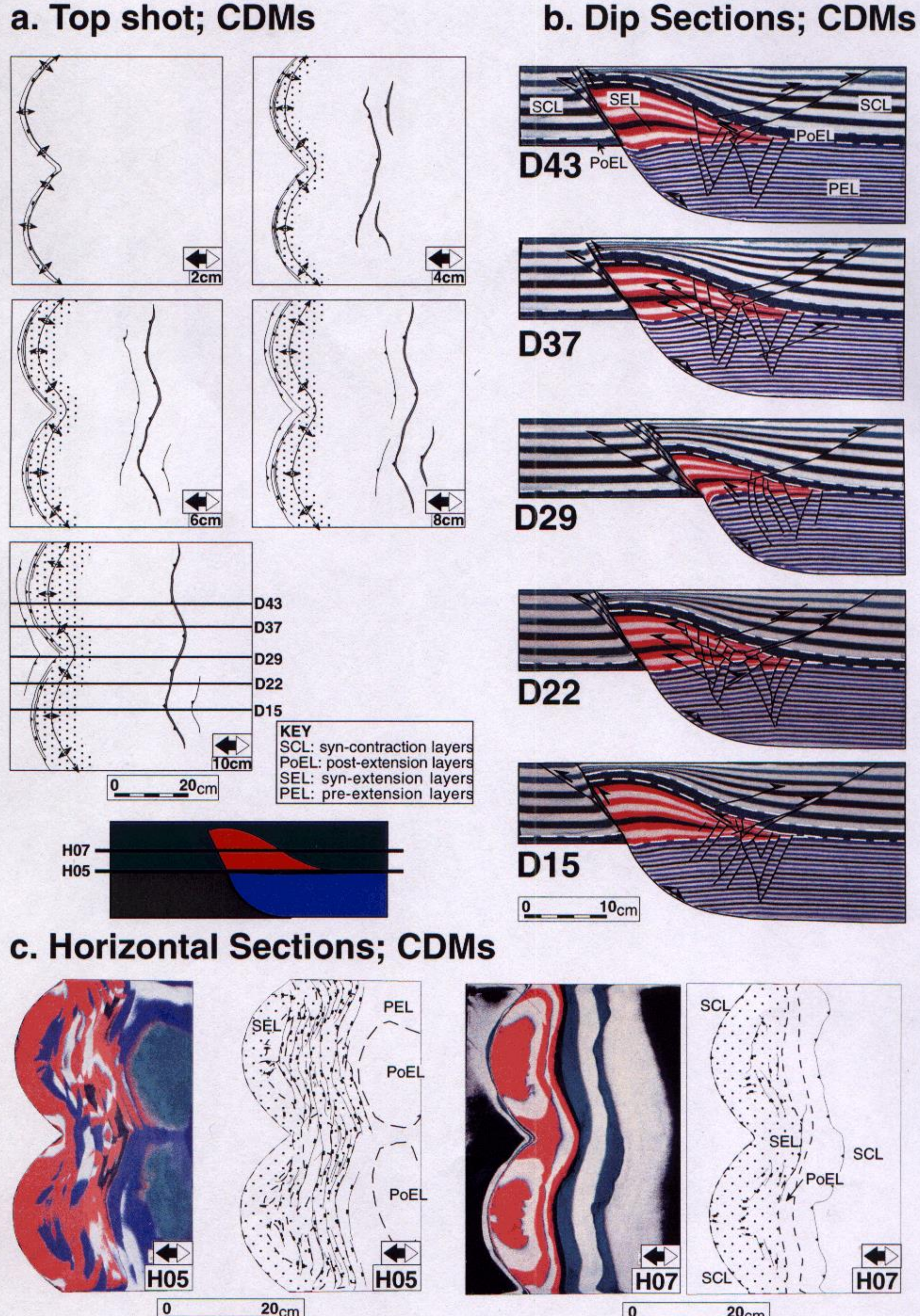
a. Top shot; CSMs
b. Dip Sections; CSMs
FW
2cm
4cm
6cm
8cm
10cm
45
41
30
19
15
0
20cm
SEL
PEL
10cm
KEY
SEL: syn-extension layers
PEL: pre-extension layers

Fig.5



a. Top shot; CSMs
2cm
4cm
6cm
8cm
10cm
D44
D37
D30
D22
D16
0 20cm
KEY
SCL: syn-contraction layers
PoEL: post-extension layers
SEL: syn-extension layers
PEL: pre-extension layers
H07
H05
b. Dip Sections; CSMs
SCL
SEL
SCL
PoEL
PoEL
PEL
D44
D37
D30
D22
D16
0 10cm
c. Horizontal Sections; CSMs
SEL
PEL
PoEL
SEL
SEL
PEL
PEL
SEL
H05
H05
0 20cm
SCL
PoEL
SEL
SCL
SCL
H07
H07
0 20cm

Y&KM
Fig.7



a. Top shot; CDMs
2cm
4cm
6cm
8cm
10cm
D43
D37
D29
D22
D15
0 20cm
KEY
SCL: syn-contraction layers
PoEL: post-extension layers
SEL: syn-extension layers
PEL: pre-extension layers
H07
H05
b. Dip Sections; CDMs
SCL
SEL
SCL
PoEL
PoEL
PEL
D43
D37
D29
D22
D15
0 10cm
c. Horizontal Sections; CDMs
H05
SEL
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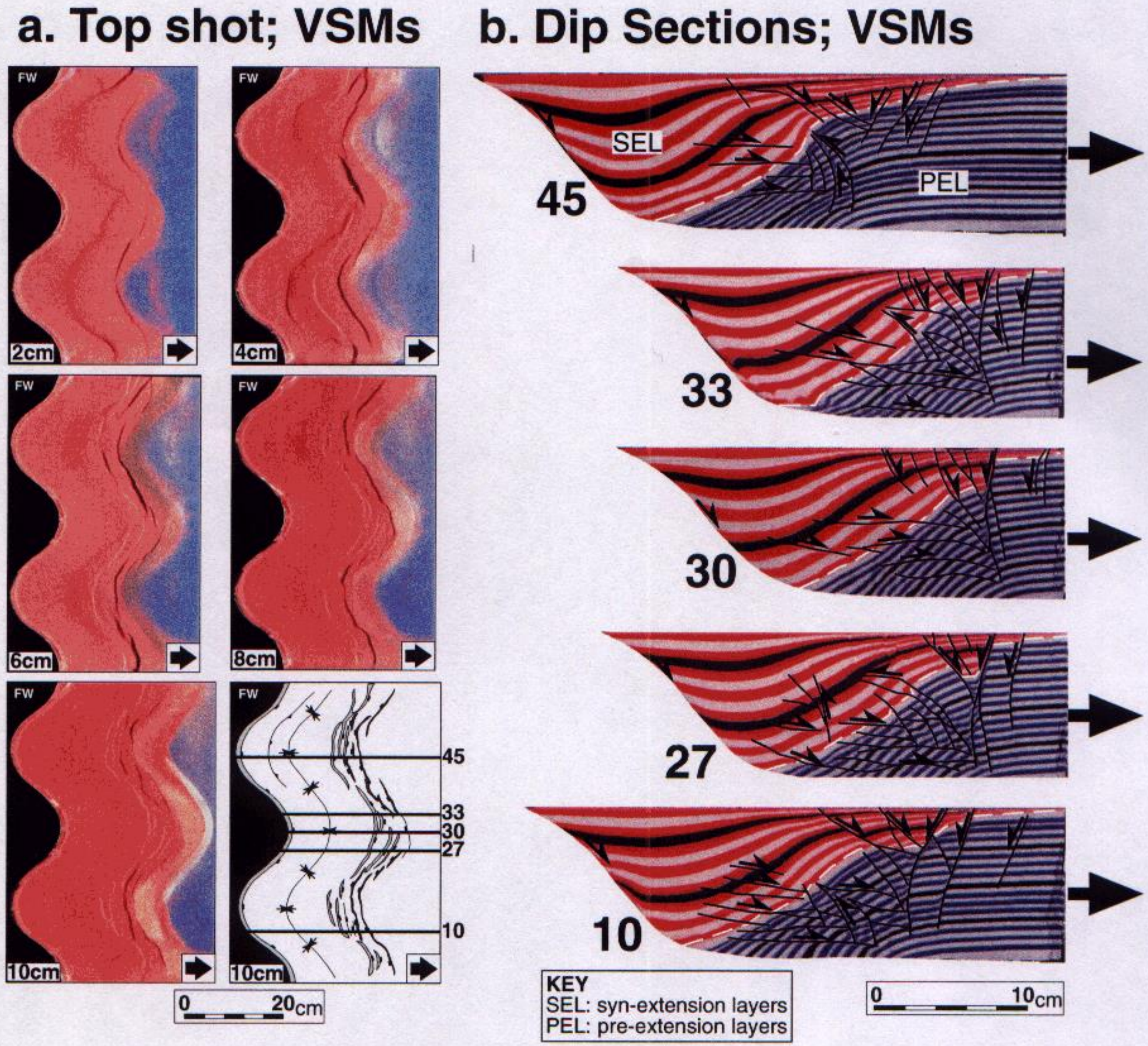
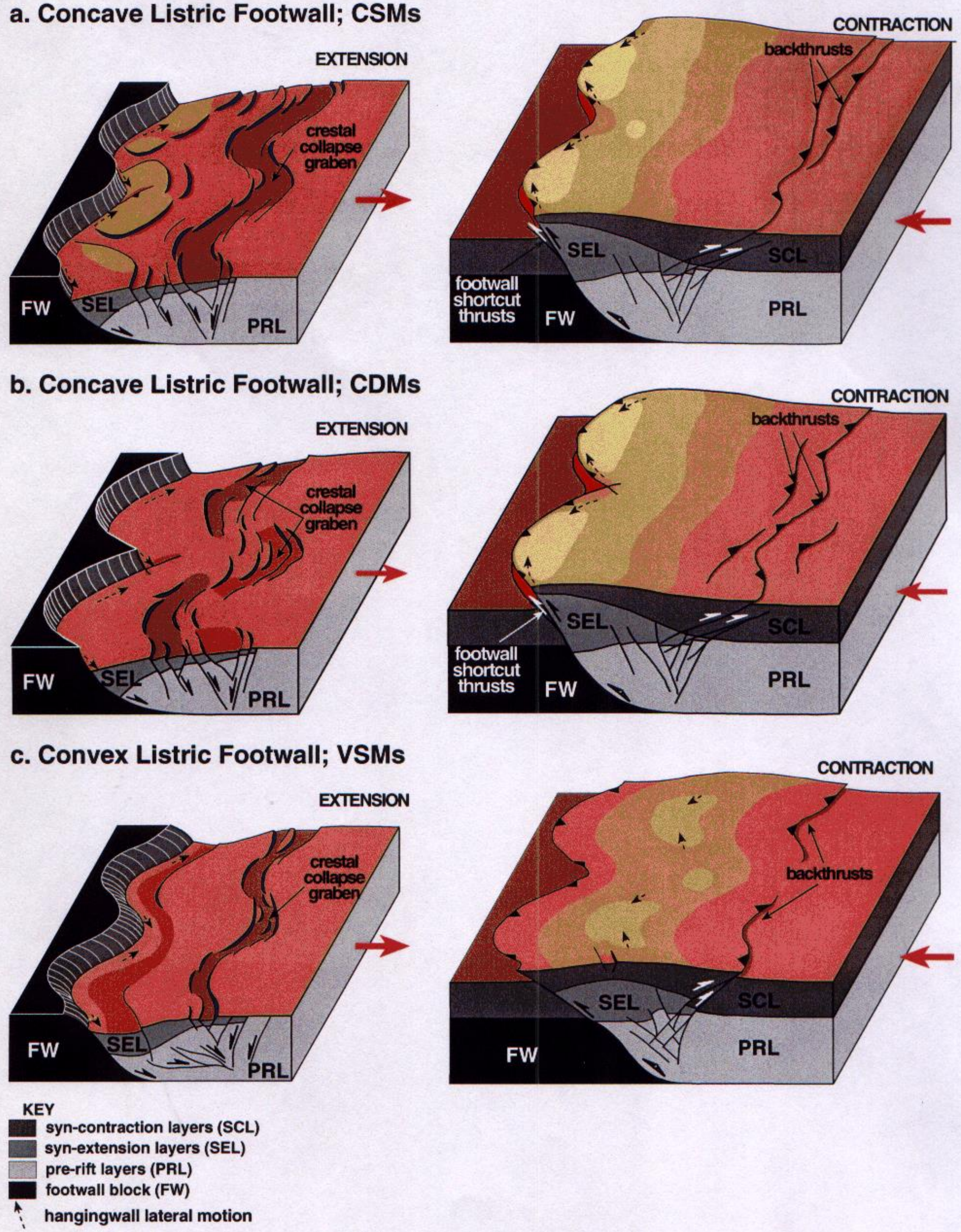
PoEL
SCL
H07
0 20cm

YY&KM
Fig.8

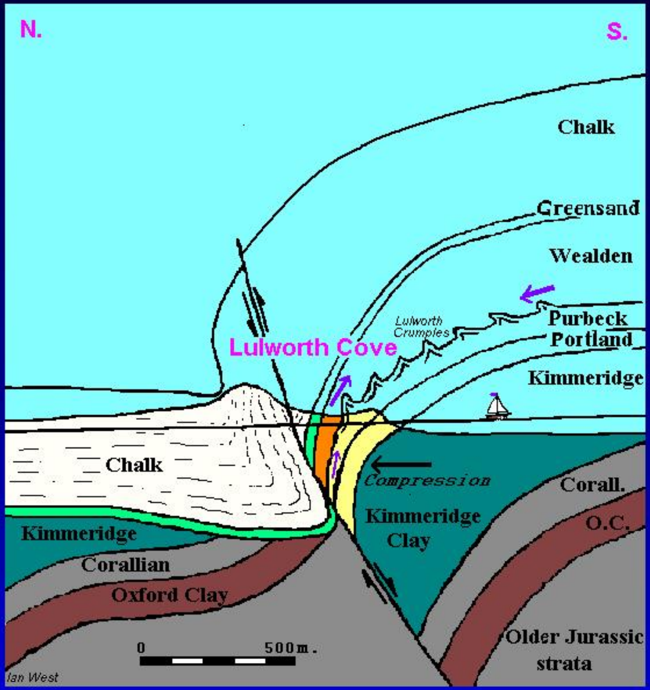

a. Top shot; VSMs
b. Dip Sections; VSMs
FW
2cm
4cm
6cm
8cm
10cm
45
33
30
27
10
SEL
PEL
0 20cm
0 10cm
KEY
SEL: syn-extension layers
PEL: pre-extension layers

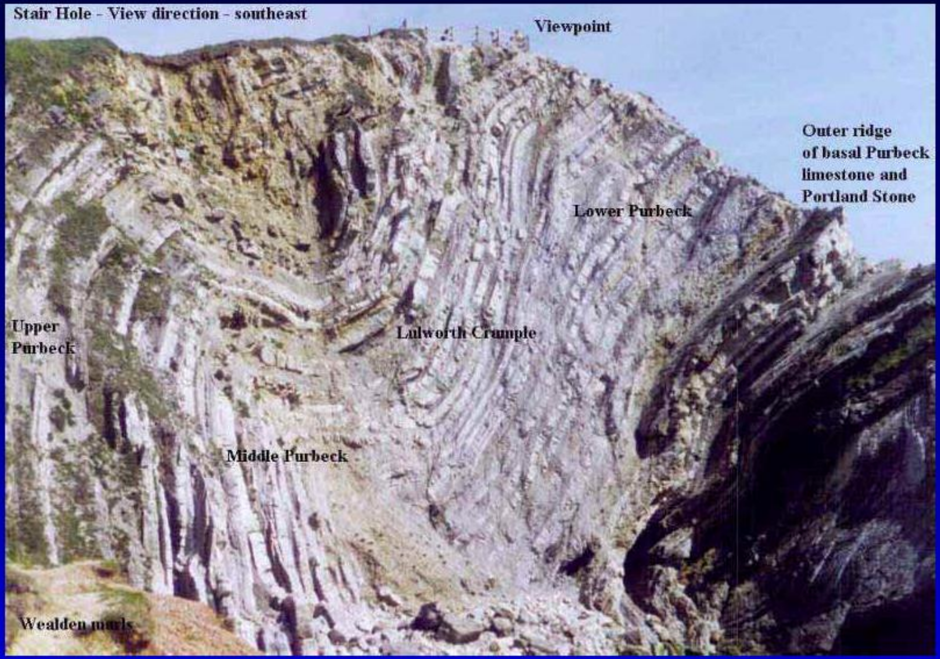
YY&KM
Fig.11

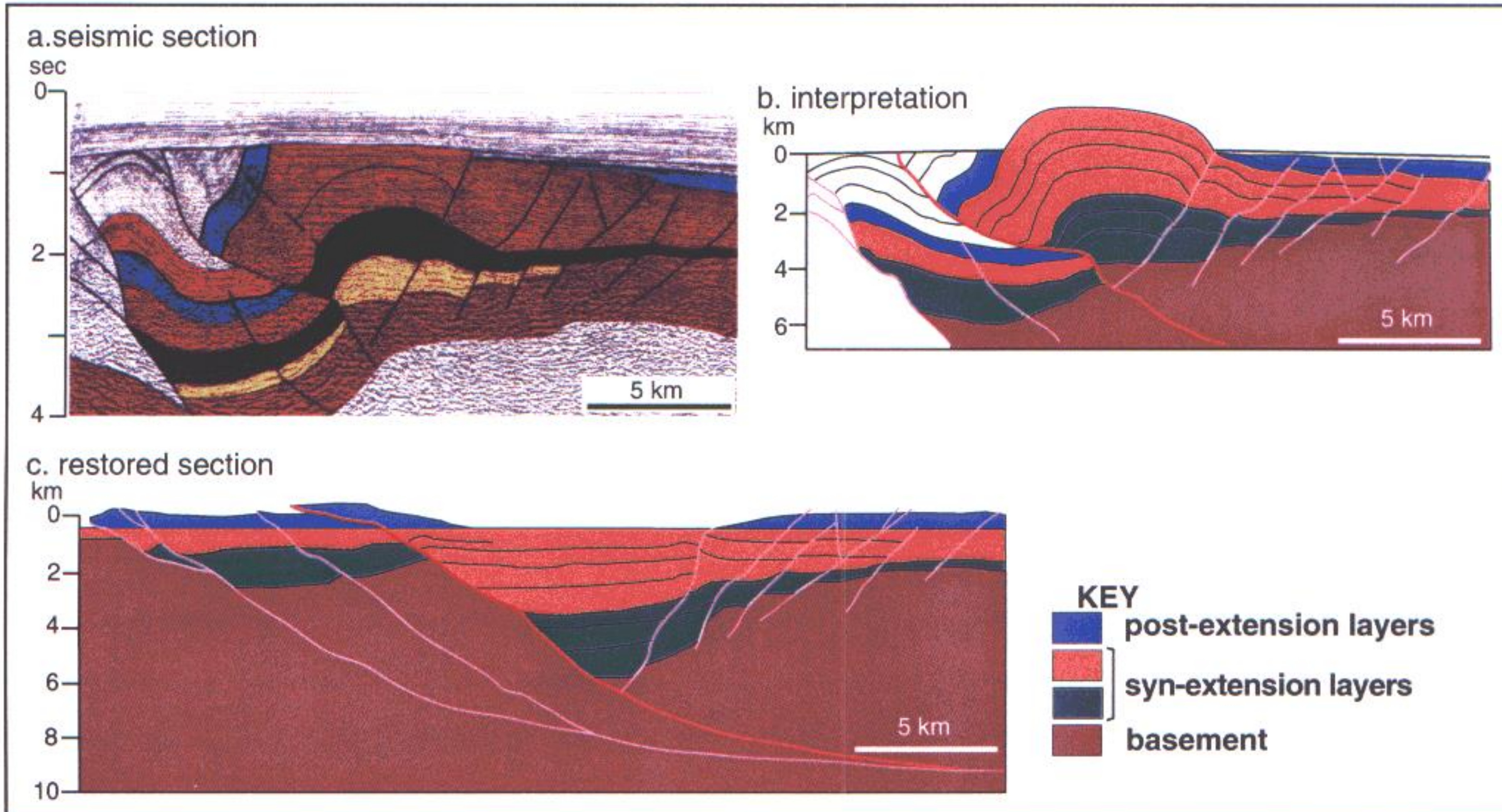


a. Concave Listric Footwall; CSMs
EXTENSION
crestal collapse graben
FW
SEL
PRL
CONTRACTION
backthrusts
SEL
SCL
footwall shortcut thrusts
FW
PRL
b. Concave Listric Footwall; CDMs
EXTENSION
crestal collapse graben
FW
SEL
PRL
CONTRACTION
backthrusts
SEL
SCL
footwall shortcut thrusts
FW
PRL
c. Convex Listric Footwall; VSMs
EXTENSION
crestal collapse graben
FW
SEL
PRL
CONTRACTION
backthrusts
SEL
SCL
FW
PRL
KEY
syn-contraction layers (SCL)
syn-extension layers (SEL)
pre-rift layers (PRL)
footwall block (FW)
hangingwall lateral motion

Inversion tectonics: Examples from NW Europe; e.g., Lulworth Cove in England







a.seismic section
sec
0
2
4
5 km
b. interpretation
km
0
2
4
6
5 km
c. restored section
km
0
2
4
6
8
10
5 km
KEY
post-extension layers
syn-extension layers
basement

Fig.13