STRUCTURAL GEOLOGY OF SEVIER FORMATION FOLDS AND FAULTS AT PHIPPS BEND NUCLEAR PLANT SITE

Report Submitted to the Tennessee Valley Authority

by

Fred Webb, Jr.

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Folds and faults at the CCW Pump Station and Turbine Building 2 sites have developed in response to the same stress system that formed the larger regional structures which include the Saltville Fault to the north and the Bays Mountain Synclinorium to the south. The stress system that produced the structures here and elsewhere in the Southern Appalachians is best described as a dominantly compressive stress that was directed along a northwest-southeast line. The minimum stress axis was approximately vertical whereas the intermediate stress axis was oriented approximately N. 45° E. Fig. 1 illustrates the general relationship of the stress axes to the structural features in the area of the Plant and the Southern Appalachians.

Although the entire sequence of rocks at the sites are classed and mapped as the Sevier Formation, rock types present consist of somewhat non-uniform alternating layers of shale, siltstone, and very fine-grained sandstone. Interbedding of these three lithologies is an important factor in the study of the mechanics of deformation because changes in rock type modify stress distribution and structural behaviour (see Whitten, 1966, p. 211, for example).

The principal mechanism of deformation at the sites is best described as flexural slip (= flexure) folding as described by Ragan (1973), Spencer (1969), Billings (1972), and Whitten (1966). Folds produced by flexure are described as having concentric (= parallel) geometry. Although there are some indicators [illegible] fractures and other planar structures oriented approximately [illegible] to axial

planes of folds, of similar folds at the site, most structures are more closely approximated by the flexural slip origin.

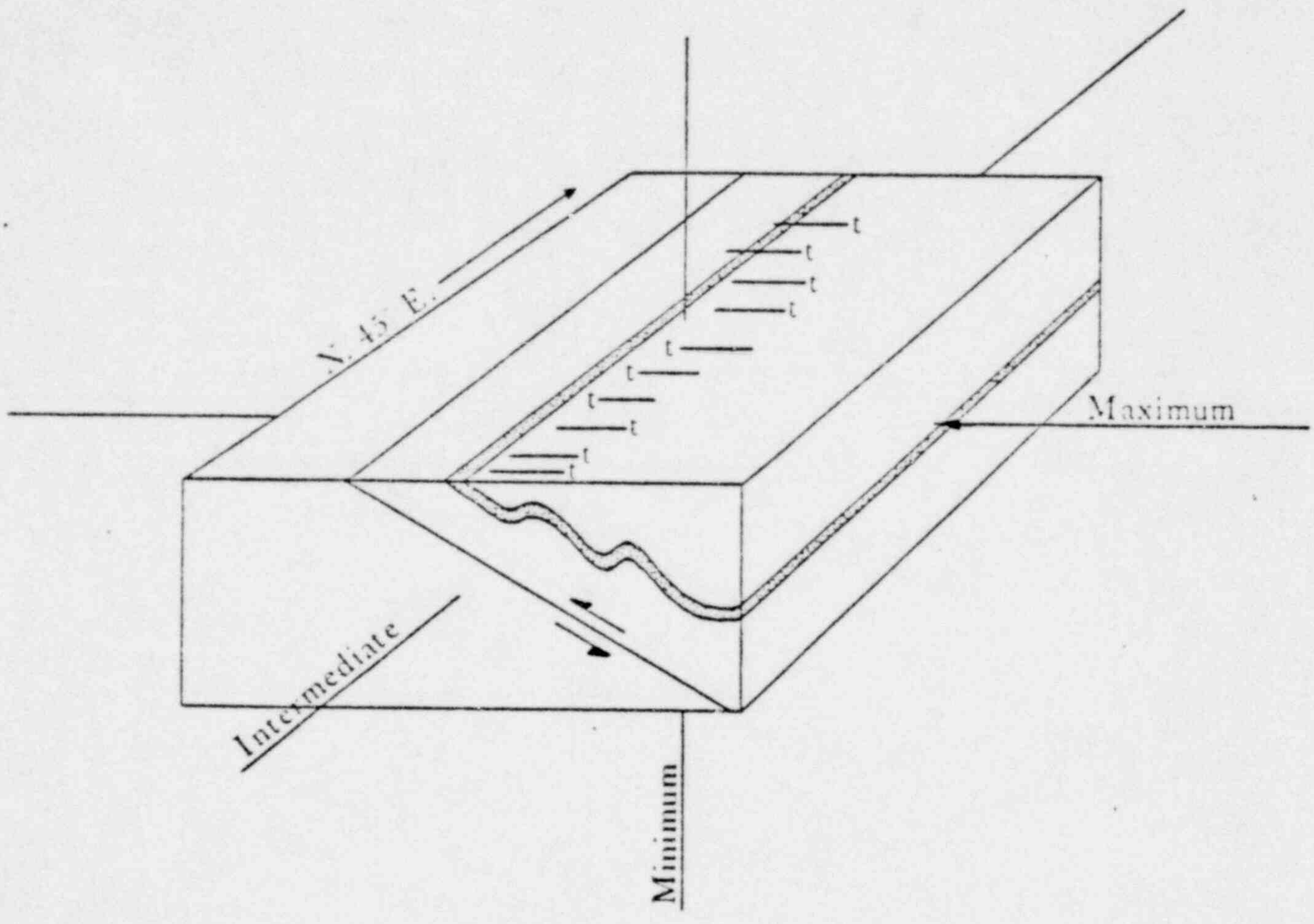

Figure 1. Orientation of stress axes compatible with structural features present in the Phipps Bend, Tennessee, area. Faults and folds are shown diagrammatically. Symbols: t = tensional fractures, arrows show relative motion of fault blocks, and axes are labelled. Modified isometric base distorts right-angle relations.

Characteristics of concentric folds generally include maintenance of both uniform bedding thickness across folds and constant bed

length in portions of individual folds (spencer, 1969; Ragan, 1973). During flexural slip deformation, individual beds in the sedimentary sequence are displaced by parallel slip or shear along bedding planes as each layer in the pile shifts upward relative to its underlying neighbor. A commonly cited example of this process is the flexing or bending of a stack of computer cards.

Where well-bedded lithologies are subjected to compressive stresses that exceed the elastic limit of the rocks, stress is accomodated by a combination of methods that include folding, some thickening and thinning, fracturing, and faulting. Gray (1979) describes these strain-accomodation structures in the southwestern Virginia area. The development of strain-accomodation structures results from the movement of incompetent material into potential hinge spaces of folds, development of limb thrust faults, shearing off of beds, and partial hinge collapse (Gray, 1979).

As sandier beds in the sequence are more competent to transmit stress than are the finer-grained shales, the shales are generally transected by more shear fractures that tend to be oriented at acute angles to bedding. Fractures in sandier beds tend to be oriented at nearly right angles to bedding. Thus, the bedding-to-fracture relationship illustrated in Fig. 2 is common.

The tendency for fracture planes to be refracted where passing from beds of differing competencies leads to the development of imbricated limb thrust faults which have curved slip surfaces and stratigraphically variable displacements. Plate 1 illustrates the type of imbrication and variable stratigraphic displacement which

are characteristic of the Appalachian region and the CCW Pump Station site. Typical crumpling and faulting that occur as a consequence of partial hinge failure are also shown in Plate 1.

Fig. 1 shows fractures of a tensional origin oriented along northwest-southeast lines. Structures at both sites where tensional origin is probable include calcite-filled gashes and lateral faults of small displacement (such as located at the Turbine Building 2 site). Inasmuch as these features developed during folding and associated thrust faulting, the tensional fractures are locally offset and folded. In other instances, however, tension fractures offset bedding, thrust faults, and folds.

Bedrock at the Plant contains calcite cement and rare beds of limestone. Thus, abundant white, coarsely crystalline calcite is present in most joints, and along bedding planes and faults. This secondary calcite was deposited in these locations by pore water redeposition following dissolution from cement and movement to the present locations. Calcite deposits with slickensides are often indicators of relative directions of movement along faults (Spencer, 1969). Slickensides along bedding or on fractures cutting across bedding indicate that the surfaces on which they are located were active boundaries duirng folding.

The sense of motion provided by slickensides is valid for only the last motion along discontinuity surfaces. Thus, interpretation of slickensides must be done with caution for minor last movement of but a fraction of an inch might mask or obliterate more extensive earlier movement in an opposite direction. Hobbs, Means, and Williams

(1976, p. 303-305) discuss the erasing and overprinting of slickensides. At the CCW Pump Station site, however, most directions of motion indicated by slickensides are compatible with those shown in Fig. 2.

Folds at the sites developed as drag folds such as those shown by Spencer (1969, p. 189 and 201), and discussed by Gray (1979). Continued application of stress produced asymmetrical folds with vertical to locally overturned beds. Consequently, bedding plane and oblique-shear slip surfaces located at vertical to overturned bedding sites show vertical to southward steeply dipping faults as shown in Plate 2.

Thus, south-dipping faults that have apparent normal displacement (as defined by Billings, 1972) are compatible with the regional structural pattern that developed prior to and contemporaneously with the Saltville fault. Complexity of structure is compounded by the general lack of unique marker beds for determination of stratigraphic displacement. Variable angles of fold plunge toward the southwest also complicates structural interpretation through creation of curving outcrop patterns of fault traces and bedding. Fold plunge also creates structural highs and lows over which beds and folds have been displaced with a component of rotational motion. Thus, individual fault displacements are non-uniform with respect to beds and structures that are transected.

In summary, there are no indications of structural features of an origin later than the Saltville fault at the Plant. All folds and faults conform to regional tectonic patterns of Late Paleozoic age.

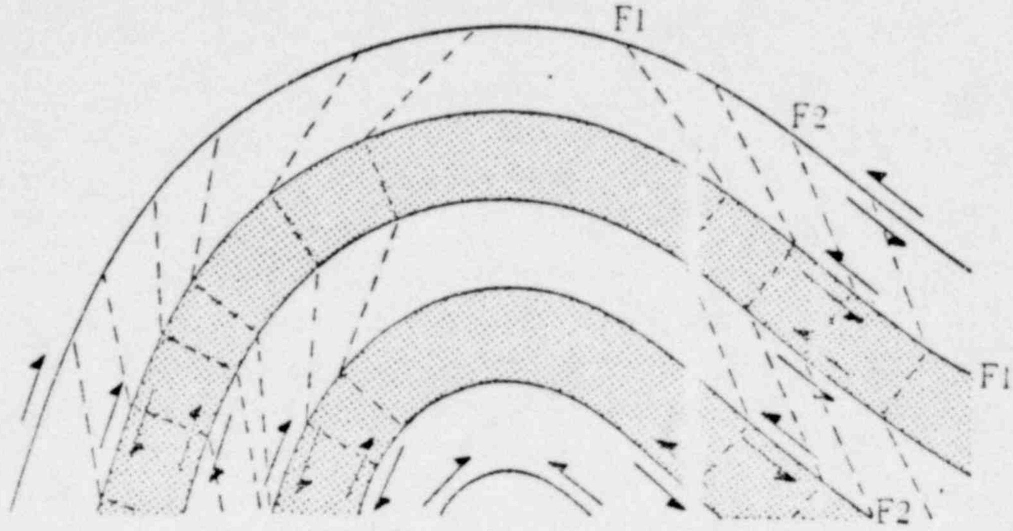

Figure 2. Typical orientation, generalized, of fractures in interbedded shales and more competent sandy units Arrows show relative movement directions along bedding planes during flexure folding; dashed lines, F1 and F2, show two examples of possible thrust fault trajectories. Stippled pattern shows sandy units; other units not marked are shaly beds.

Explanatory Text for Plates 1 and 2

Plate 1 shows three stages in the evolution of faults and folding such as are present at the sites. Chronological order is indicated by numbers 1 - 3 (oldest to youngest). Eventual lines of faulting are shown by dashed lines. Faults are labelled FF and F'. Beds are labelled 1 - 5 for purposes of showing displacement along faults. Note that as folding becomes progressively tighter, bedding plane thrust becomes imbricate as fault F' forms. Arrows show relative motions along faults. Note that bed 2 in the sequence on the hanging wall block is in apparent conformable sequence with respect to bed 1 of the footwall block in places where the bedding plane thrust occurs. However, the imbricate block in stage 3 has considerably more structural discordance across the fault.

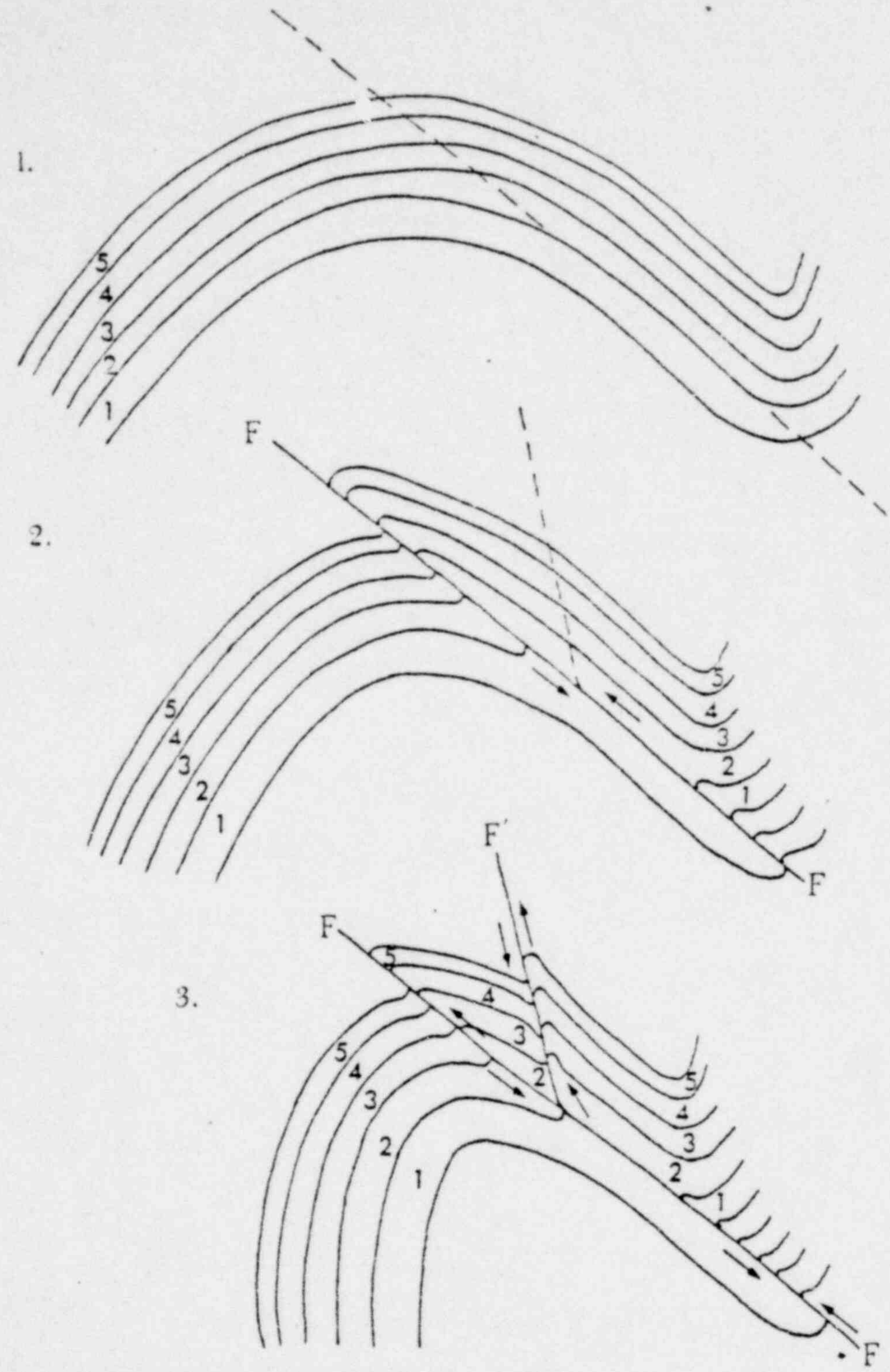

Plate 1. Development stages in formation of imbrication and variable stratigraphic displacement characteristic of the Phipps Bend area. Note crumpling and faulting that occur as partial hinge collapse occurs. FF and F' show faults; arrows indicate movement directions.

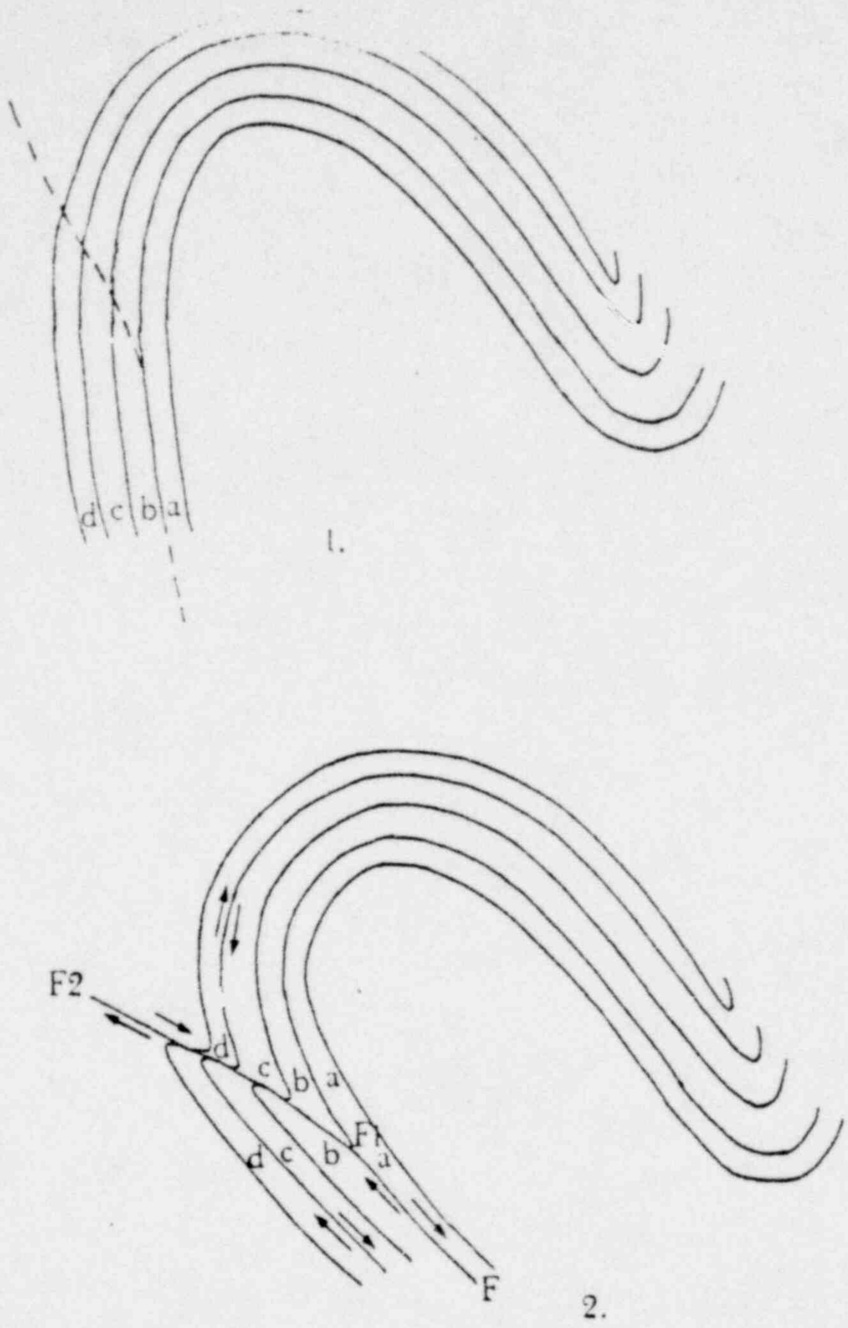

Plate 2. Orientation of oblique-shear and bedding-plane slip surfaces associated with development of strong asymmetry of folds. Top sketch, numbered 1, is initial stage while number 2 sketch is later faulted stage. Note that from F to F1 fault is overturned thrust parallel to bedding and that from F1 to F2 the fault is oblique to bedding. Letters a - d on beds are for matching purposes.

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Plate 2 illustrates an initial and final stage in the development of overturned bedding-plane and oblique-shear thrust faults that have an apparent "normal" sense of motion. Note that as the fold becomes tighter the fault labelled F-F1-F2 develops along the line shown as a dashed line in sketch 1. The displacement along the fault progressively becomes more pronounced as the fault becomes oblique to bedding between F1 and F2.

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