THE SALTVILLE THRUST: INVESTIGATION OF A REGIONAL THRUST FAULT IN A FORELAND FOLD AND THRUST BELT

by

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INTRODUCTION

Thin-skinned models of deformation (Rich, 1934; Rodgers, 1949) have gained wide acceptance in Appalachian geology, but little detailed analysis exists of Valley and Ridge thrusts in the southern Appalachians, in terms of fault zone character and mechanisms of thrust propagation and emplacement. The object of this thesis is to provide detailed data and analyses of the Saltville thrust of the southern Appalachians. This is done in two papers, each dealing with different aspects of the thrust. Critical issues, which are examined include: thrust-fold relationships at the northern terminus, regional displacement transfer mechanisms, modes of thrust propagation and emplacement, operative deformation mechanisms, and the relationships between fault-rock fabrics and sliding mechanisms.

MESOSCOPIC DEFORMATION FABRICS AT THE NORTHERN TERMINUS OF THE SALTVILLE THRUST: IMPLICATIONS FOR THRUST PROPAGATION

INTRODUCTION

Current models for thrusting and associated deformation in the southern Appalachians have their origin in Rich's (1934) studies of the Cumberland overthrust block. Inherent in these models is the concept of thin-skinned deformation (Rodgers, 1949). Folding and faulting is due to movement along low angle shears in the foreland sedimentary wedge. Subhorizontal décollements form in incompetent strata and enable overthrust blocks to move, eliminating basement involvement. Progressive movement along a master décollement results in upward migration of the fault through the sedimentary pile, in a step-like fashion (e.g. Harris and Milici, 1977). Other thrusts occur as listric-shaped features which merge at depth with sole thrusts. Shear thrusts, which cut through flat-lying strata, and break thrusts, which cut previously folded strata, have been recognized (Willis, 1894).

Knowledge of thrust geometry and relationships of thrusts to enclosing strata are important to our understanding of thrust propagation in foreland zones. These features can be directly studied in terminal portions of thrusts. Previous research on thrust terminations is partially summarized in Dahlstrom's (1970) studies of displacement transfer. Model studies of overthrusting have recognized the transition from faulting to conical folding as a primary means of producing displacement transfer (Gardner and Spang, 1973). Field work has demonstrated that thrusts will propagate from areas where fold axes converge (Ollerenshaw, 1968), and that thrust splays do not end at fault trace terminations, but continue laterally in the subsurface where they intersect a master thrust surface (Brown and Spang, 1978).

Little detailed work has been done on terminations of regional overthrusts in the southern Appalachians. This paper describes structural relationships at the northern terminus of the Saltville thrust, a regional thrust in the southern Appalachians. The thrust terminates in the Sinking Creek anticline. Displacement transfer requires constant shortening in a structural block as displacement along a thrust decreases. This may cause development of a terminal anticline during thrust propagation. Fold formation is either passive due to upwarping as hanging wall strata move over a ramp (Harris and Milici, 1977), or active due to buckle shortening above a décollement surface (Dahlstrom, 1969, 1970; Laubscher, 1977). Both modes of folding will have different deformation intensity patterns and different distributions of mesoscopic structures. This paper attempts to use both aspects to define the folding style for the Sinking Creek anticline and to establish the mechanics of displacement transfer.

The investigation involved geologic mapping and analysis of the mesoscopic fabric (Norris, 1958; Fitzgerald, 1963; Price, 1964, 1967). Fabric elements used include: calcite-filled extension fractures, faults, folds, cleavage, tectonic stylolites, slickenside striae, en echelon gash veins, and bedding. The deformation at the northern terminus of the Saltville thrust was studied to define thrust propagation, thrust-fold relationships, operative displacement transfer mechanisms, and local deformation history.

GEOLOGIC SETTING

The Valley and Ridge province of the southern Appalachians lies in the foreland thrust-fold belt of the Appalachian orogen. It is characterized by an array of interleaved thrust-sheets separated by arcuate, discrete, discontinuous fault traces which truncate regional anticlinoria and synclinoria (Fig. 1). Regional thrusts trend N/55/E and extend hundreds of kilometers. They terminate in southwestern Virginia at the juncture

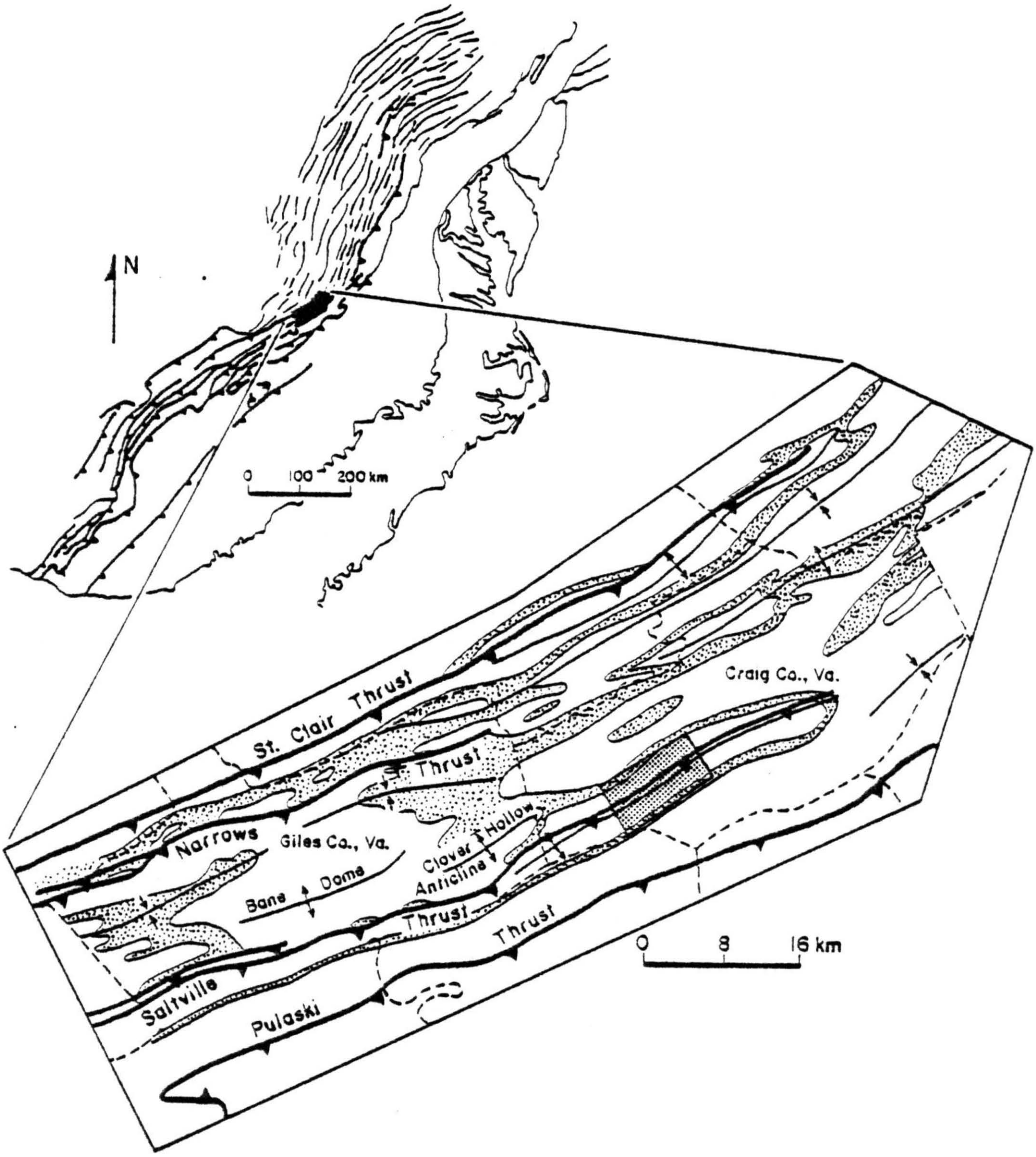


Fig. 1. Index map showing regional geologic structure. Silurian outcrops are stippled. Shaded box defines study area.

between the southern and central Appalachians, where regional strike changes to N/35/E, and folding dominates the structural style.

The Saltville thrust has a strike length of 690 km and extends from southwestern Virginia into northern Alabama where it is known as the Rome thrust. The thrust in Virginia and Tennessee dips southeast and is characterized by variations in dip of the fault surface: 10 - 30 degrees in Tennessee (Haney, 1966); 30 degrees average in Virginia and Tennessee (Rodgers, 1970); 0 - 30 degrees at Saltville, Virginia (Muangnoicharoen, 1978); and 50 degrees at Goodwins Ferry, Virginia. The thrust, in general, has moderate to steep dips in southwestern Virginia.

Along much of its length in Virginia and Tennessee, the Saltville thrust overrides Mississippian strata of the Greendale syncline. The syncline dies out up plunge to the northeast, and is not detectable at the northern terminus of the thrust. The Blacksburg synclinorium lies southeast of the thrust terminus. The trough of this structure is largely covered by the Pulaski thrust-sheet. Other prominent structures include the Bane Dome, Clover Hollow anticline (Fig. 1), and John's Creek syncline, which is adjacent to and northwest of the Sinking Creek anticline. Maximum stratigraphic throw on the Saltville thrust occurs at the Virginia-Tennessee border where Cambrian Rome shale is thrust northwest over Mississippian limestone and shale. Elsewhere, Cambrian Honaker Dolomite commonly forms the hanging wall, except in the Sinking Creek anticline, where Knox Dolomite comprises the hanging wall.

STRATIGRAPHY

The stratigraphy in the study area (Fig. 1) is given by Butts (1933, 1940), Cooper (1944a, b, 1945, 1961), Hobbs (1953), Ovenshine (1961), Bregman and Francis (1973), and Gambill (1974). The sequence ranges from Middle Cambrian to Devonian (Fig. 2). Detailed lithologic descriptions are given in Appendix 1.

Cambrian Rome shale is not exposed along northern portions of the Saltville thrust. It is found to the east along the Pulaski thrust-sheet and in the Bane Dome to the southwest. The shales are fissile and noncalcareous with interbeds of limestone and dolomite. Middle Cambrian Honaker Dolomite overlies Rome shale. Lower units in the Honaker Formation are thin-to-medium-bedded and upper units are thick-bedded. They are overlain by thin-bedded, fine-grained argillaceous limestone of the Nolichucky Formation.

The oldest lithologies recognized in the field area

STRATIGRAPHIC COLUMN		Thickness (meters)	Litho-tectonic Characteristics
Devonian	Devonian Clastics		
Silurian	Silurian Sandstone	213	competent
Ordovician	Juniata Fm.		
	Martinsburg Fm.	305	incompetent
	Moccasin Fm.	76	
	Witten Fm.	305	competent
	Benbolt Fm.		
	Lincolnshire Fm.		
	Five Oaks Fm.		
	Blackford Fm.		
	Knox Group	700	competent
Cambrian	Nolichucky Fm.	30	incompetent
	Honaker Fm.	425	competent
	Rome Fm.		incompetent

Fig. 2. Stratigraphic column near the northern terminus of the Saltville thrust.

are Knox Group dolomites. Feldspathic sandstone, sandy dolomite, and chert of the Copper Ridge Formation occur in the basal Knox. They are overlain by thin-to-medium-bedded dolomite of the Chepultepec Formation, Longview lime mudstones, and Upper Knox Kingsport and Mascot dolomites.

Middle Ordovician limestones of the Blackford, Five Oaks, Lincolnshire, Benbolt, and Witten formations are separated from the Upper Knox by an unconformity on which tens of meters of relief may occur (Gambill, 1974; Mussman, 1980). Upper parts of the Ordovician sequence include calcareous mudrock of the Moccasin Formation, thin-bedded limestone and shale of the Eggleston Formation, interbedded shale and lime packstone of the Martinsburg Formation, and Upper Ordovician siltstone and sandstone of the Juniata Formation. Silurian quartzite and Devonian sandstone and shale complete the stratigraphic succession.

TERMINUS OF THE SALTVILLE THRUST

The Sinking Creek anticline is a northwest facing, overturned fold (Fig. 3). It plunges northeast with fold closure at the juncture between the central and southern Appalachians (Bregman and Francis, 1973). Plunges on the structure are subhorizontal to the southwest and steepen

Fig. 3. Geologic map of study area (see Fig. 1). OCk - Knox Group, Ols - Middle Ordovician limestones, Su - Silurian undivided.

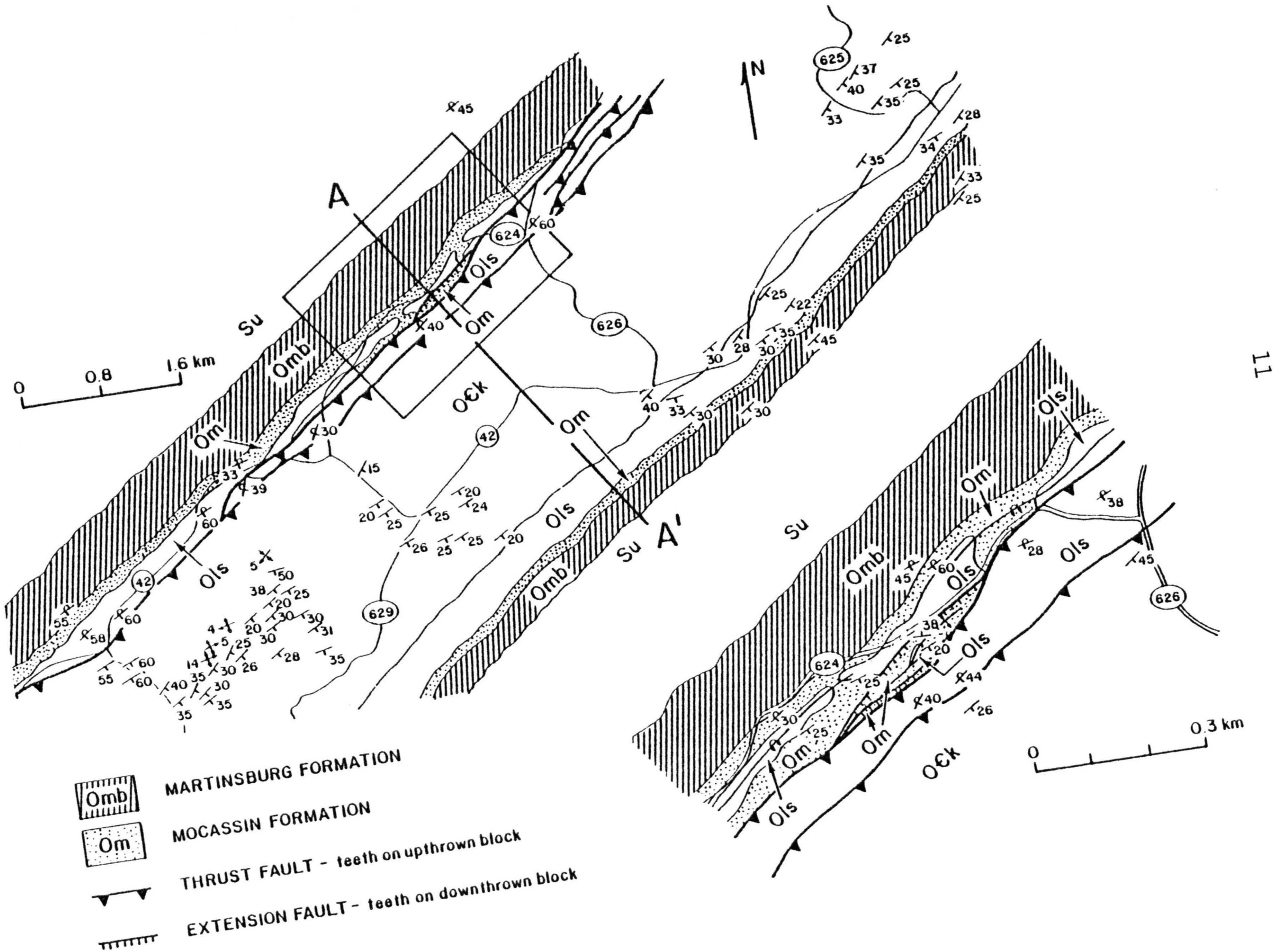
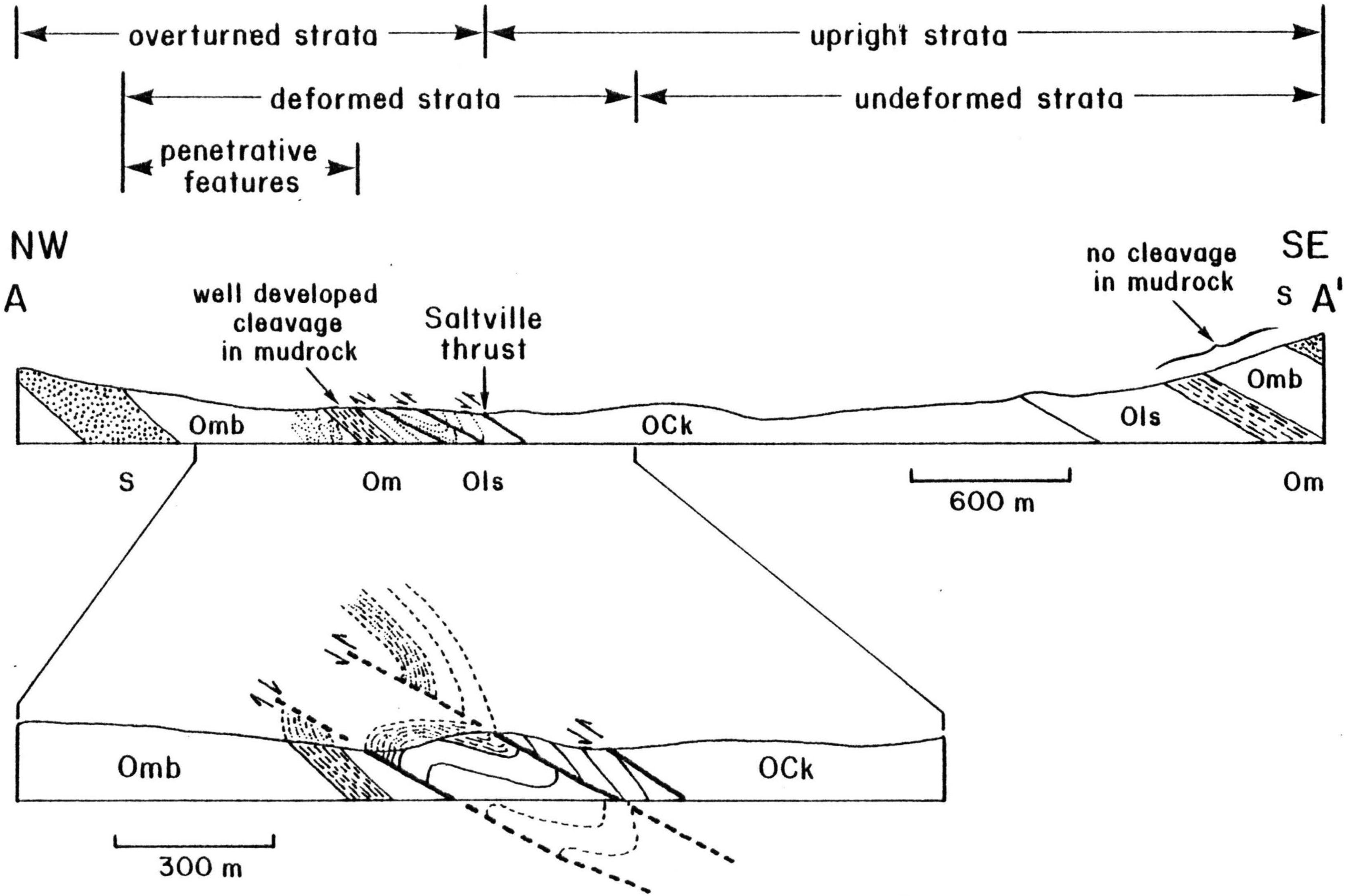

A
A'
N
Su
Omb
Om
Ols
O€k
0
0.8
1.6 km
0
0.3 km
624
625
626
42
629
Omb MARTINSBURG FORMATION
Om MOCASSIN FORMATION
THRUST FAULT - teeth on upthrown block
EXTENSION FAULT - teeth on downthrown block

Fig. 4. Cross section from study area.(line A-A′ in Fig. 3).



overturned strata
upright strata
deformed strata
undeformed strata
penetrative features
NW
A
SE
A'
well developed cleavage in mudrock
Saltville thrust
no cleavage in mudrock
S
Omb
OCk
Ols
Omb
Om
S
Om
Ols
600 m
Om
Omb
OCk
300 m

to 30 degrees at the northeast end. The structure has a southern Appalachian trend (N/55/E), but exhibits a "kink" at its northeastern end where the axial trend changes to N/65/E. Southern Appalachian structures obliquely interfinger with folds of the central Appalachians. The kink in the Sinking Creek anticline may be due to folding around a central Appalachian trend (Rodgers, 1970). Regional folds in the juncture zone have half wavelengths of 5 km. Interference from other regional folds causes the anticline to end 33 km southeast of the fold nose (Fig. 1).

The Saltville thrust displaces strata along the entire length of the anticline and breaches the anticlinal nose. The thrust trace does not bisect the anticline, but lies on the northwest side of the structure. Thrusting places Knox Group dolomite over Middle Ordovician limestone. The Knox Group is stratigraphically right side up southeast of the thrust trace, and is 1100 - 1200 meters thick. This is 1.5 - 2.0 times the normal thickness. Middle Ordovician through Silurian units on the northwest limb are overturned with dips averaging 30 to 45 degrees southeast. Strata on the southeast limb show no penetrative deformation, are upward facing, and dip 25 degrees southeast. The northwest limb has an abnormal thickness of Martinsburg (twice normal thickness).

FOOTWALL STRUCTURE AND FABRIC ELEMENTS

Folding: Penetrative deformation associated with Saltville thrust emplacement is concentrated in the footwall block (Figs. 3 & 4). Folding, faulting, cleavage development, and penetrative strain occur in Ordovician footwall strata (Fig. 6 & Table 1). Tight to isoclinal mesoscopic folds truncated by faults have caused tectonic thickening in the Martinsburg Formation (Fig. 4). The largest structure is a macroscopic fold that deforms Moccasin mudrock and Middle Ordovician limestone. It is a northwest facing, overturned anticline which occurs 18 km southeast of the nose of the Sinking Creek anticline. The fold hinge is traceable for 3.2 km and has a half wavelength of greater than 30 meters. The upright limb contains open, mesoscopic folds (wavelengths of 4 meters and amplitudes of 25 cm; Fig. 5), which deform Moccasin mudrock and Middle Ordovician limestone. Other minor folds involving Knox Dolomite in the hanging wall include: open folds with wavelengths of several meters and amplitudes of less than a meter (1200 meters southeast of the fault trace; Fig. 3), and small folds (wavelengths of 2 meters) adjacent to the thrust surface.

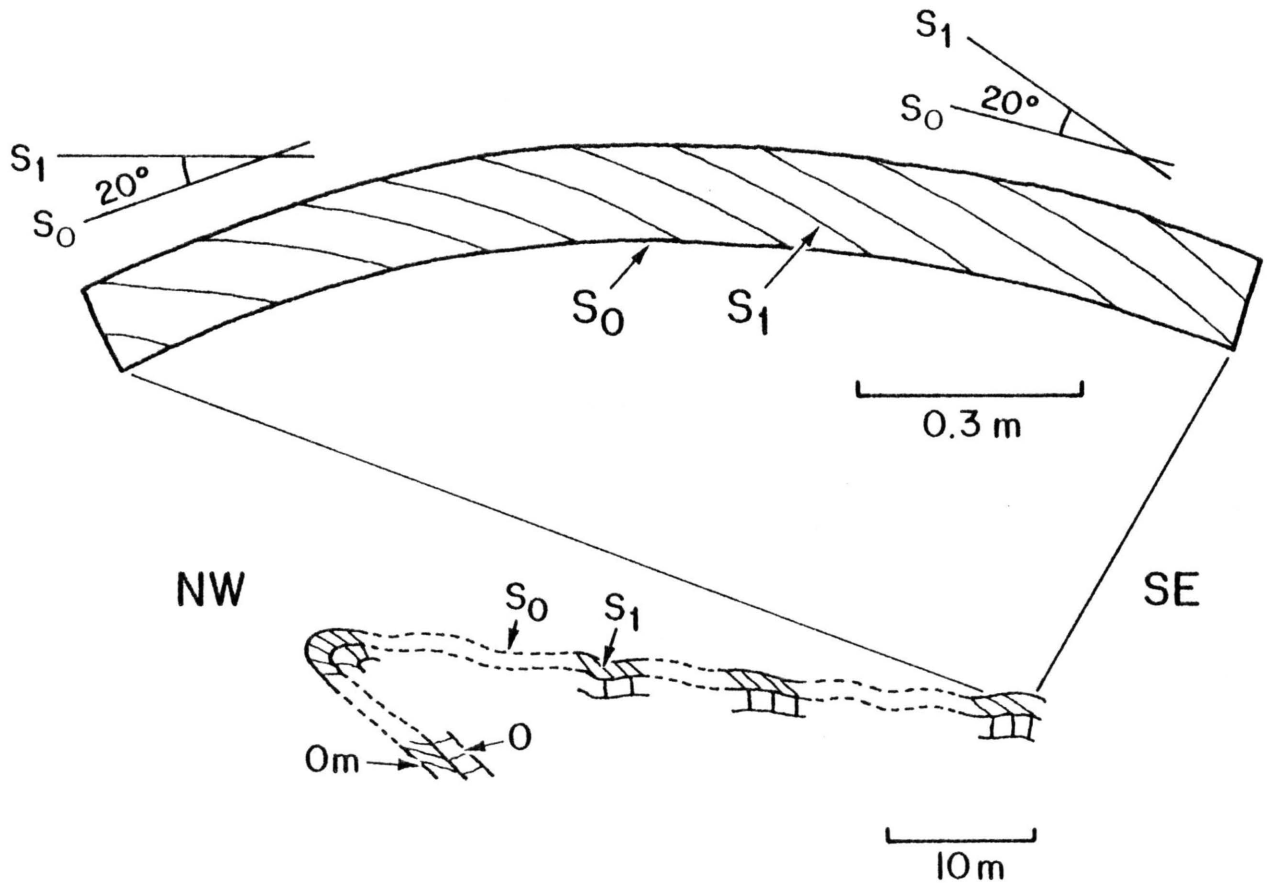
Cleavage: Cleavage occurs in Moccasin mudrock and

Table 1

Lithologies Involved	Fold Description	Axial Plane Attitude	Plunge
Martinsburg Fm.	Isoclinal Folds	N64E/40SE	27/S40W
Moccasin Fm. & Middle Ord. ls.	½ wavelength 30 meters	N55E/30SE	4/S45W
Moccasin Fm. & Middle Ord. ls.	½ wavelength 2 meters		10/S55W

Fold data from the footwall block of the Saltville thrust.

Fig. 5. Fold-cleavage relationships in folds of the footwall block of the Saltville thrust. S_1 - cleavage, S_0 - bedding, Om - Moccasin Fm., Ols - Middle Ordovician limestones.



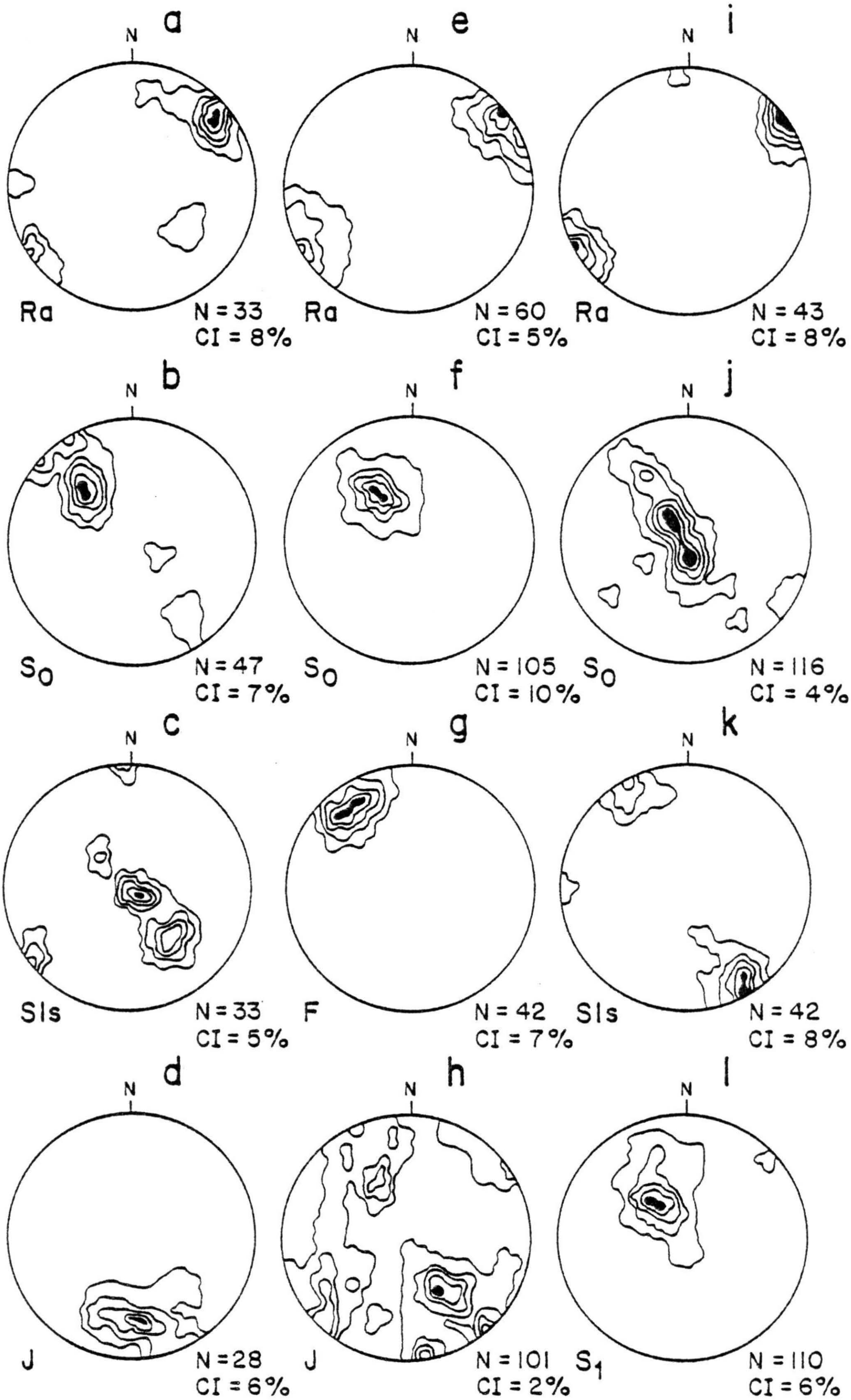
S_1
S_0
20°
S_1
S_0
20°
S_0
S_1
0.3 m
NW
SE
S_0
S_1
0
0m
10m

Middle Ordovician limestone. Cleavage morphologies in the mudrock include a weak, penetrative, slaty cleavage (cf. Powell, 1979), and a more widely spaced (0.5 cm) anastomosing variety. Cleavage is axial planar to the overturned macroscopic fold (Fig. 6i), but is deformed by open folds on its upright limb (Fig. 5). The cleavage-bedding angle on open folds is constant between limbs. Mudrock cleavage is continuous with spaced cleavage (tectonic stylolites) in the limestones. Tectonic stylolites are at high angles to bedding and fan around both sets of folds. In contrast, cleavage is lacking in mudrock on the southeast limb of the Sinking Creek anticline.

Faulting: Contractional and extensional faults occur in the footwall block (Fig. 3) and their traces are subparallel to fold hinges. Contraction faults with strike-lengths of 1 to 2 km are probably splay thrusts associated with the main Saltville thrust. Macroscopic extensional faulting displaces Moccasin mudrock (Fig. 3). Numerous mesoscopic faults with slickensides occur in the Martinsburg Formation (Fig. 6g). The faults truncate folds, and define an extensional stress system (Fig. 7), when analyzed in conjunction with extensional fractures (cf. Ragan, 1973, p. 153).

Fabric Analysis: Kinematic and chronologic rela-

Fig. 6. Equal area projections of fabric data N-sample size, CI-contour interval, Ra-rotation axes, S_0-bedding plane poles, Sls-slickenside striations, F-fault poles, J-poles to extension joints, S_1-cleavage poles, (a-d)-data from Elway and Lincolnshire limestones, (e-h)-data from lower portions of Martinsburg Formation, (i-l)-data from Witten and Moccassin formations.


a
N
Ra
N = 33
CI = 8%
e
N
Ra
N = 60
CI = 5%
i
N
Ra
N = 43
CI = 8%
b
N
S_0
N = 47
CI = 7%
f
N
S_0
N = 105
CI = 10%
j
N
S_0
N = 116
CI = 4%
c
N
Sls
N = 33
CI = 5%
g
N
F
N = 42
CI = 7%
k
N
Sls
N = 42
CI = 8%
d
N
J
N = 28
CI = 6%
h
N
J
N = 101
CI = 2%
l
N
S_1
N = 110
CI = 6%

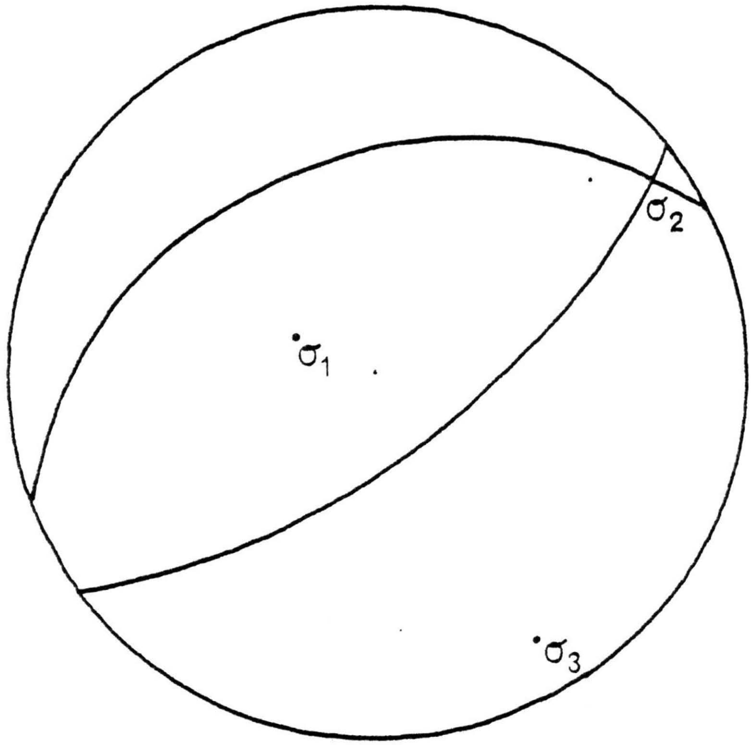


Fig. 7. Stress analysis of faults and extension fractures in the Martinsburg Formation. Sigma 1 represents the maximum principle compressive stress. The near vertical orientation indicates an extensional system.

tionships between structural features were analyzed with mesoscopic fabric elements (Fig. 6). The elements identify local displacement directions and taken as an aggregate, they define bulk deformation mechanisms. Rotation axes (kinematic b-axes), defined by fold hinges and lines perpendicular to slickenside striations (in the plane of the striations) have the same orientation in different lithologies of the footwall block (Figs. 6a, e, i).

MESOSCOPIC FAULTING, FOLDING, AND CLEAVAGE DEVELOPMENT: A DISCUSSION

Folding and Cleavage: Folds in the mudrock and Middle Ordovician limestones formed by a flexural slip mechanism. This is indicated by slickenside striations on bedding surfaces around fold hinges (cf. Figs. 6j & k).

Fold-cleavage relationships reveal kinematic and chronologic aspects of deformation. Lack of cleavage on the southeast limb of the Sinking Creek anticline indicates that: 1) a variation in strain occurs across the structure, and 2) no significant layer parallel shortening occurred. Since cleavage is confined to the overturned northwest limb, it is either related to higher strains along the overturned limb, or increased deformation intensity associated with propagation of the Saltville thrust. Fold-cleavage relationships establish three generations of folds. The regional Sinking Creek anticline is a first generation structure initiated prior to cleavage development. The overturned macroscopic folds in the footwall are second generation, and have associated cleavage. The open, upright mesoscopic folds on the subhorizontal upright limbs of macroscopic folds are third generation structures which post-date cleavage formation. All fold generations probably developed close in time, and are related to the propagation of the Saltville thrust.

Folds and Faults: Relationships between mesoscopic faults and the three fold generations are not clear. Most faults truncate existing folds. It is suggested that folding and contraction faults were closely associated, and preceded the extension faulting. No structural features cut the extension faults, and they are considered the last phase of deformation.

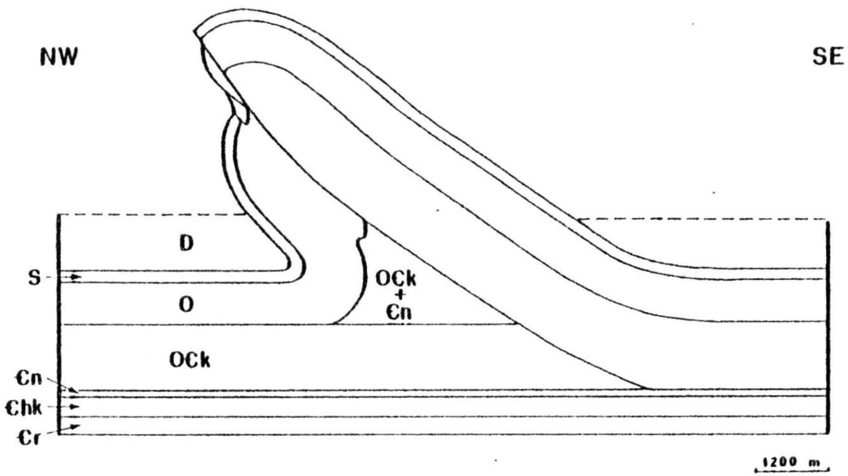
Rotation axes from structures in all lithologies have the same orientations which indicates that all deformation at the northern terminus of the Saltville thrust is co-axial. Folding, cleavage development, and faulting occurred during a single, protracted deformation associated with emplacement of the Saltville thrust-sheet.

THRUSTING MODELS

Two balanced cross sections, based on field data (Figs. 3 & 4) and geometric constraints, present different structural interpretations for development of the Sinking Creek anticline (Figs. 8 & 9). Assuming 1) plane strain deformation, and 2) flexural slip folding, the sections were balanced by restoring them to a horizontal position and checking that bed lengths at different levels in the structure were the same (cf. Dahlstrom, 1969; Hossack, 1979; Elliott, 1980). Geologic cross sections which do not balance cannot be correct (Dahlstrom, 1969). Constraints for construction of the cross sections included:

> Field Data: 1) orientation data and stratigraphic contacts, 2) the asymmetry of the Sinking Creek anticline (overturned, northwest facing fold), 3) homoclinal dip of bedding in the Knox across the fold (i.e. no marked folding of the Knox Group), 4) the Knox Group is upward facing with a known stratigraphic thickness of 1200 meters, 5) the footwall sequence of strata is overturned, 6) well developed cleavage is present on the northwest limb and is lacking on the southeast limb, and 7) mesoscopic deformation and penetrative strain are most intense on the northwest limb.
>
> Geometric Constraints: 1) depth to the master décollement surface which is about 3.5 km (Snelson, 1972, 1975), 2) fold closure occurs 16 km northeast of the field area, 3) thickness of Knox exposed in the anticline is 1.7 times that of normal stratigraphic thickness, and 4) thickness of the

Fig. 8. A balanced model of thrust-fold relationships near the northern terminus of the Saltville thrust, and the restored section. Shaded areas represent the amounts of Knox and Nolichucky needed to fill the void at the synclinal hinge. The model is based on the following assumptions: 1) detachment occurs in the Nolichucky, 2) thickening of the Knox occurred early in the deformation history, and 3) Middle and Upper Ordovician strata (excluding the Juniata Fm.) may be treated as a single unit. D-Devonian undivided, S-Silurian undivided, O-Middle and Upper Ordovician undivided, OCk-Knox Group, Cn-Nolichucky Formation, Chk-Honaker Dolomite, Cr-Rome Formation.


NW
SE
D
S
O
OЄk
+
Єn
OЄk
Єn
Єhk
Єr
1200 m

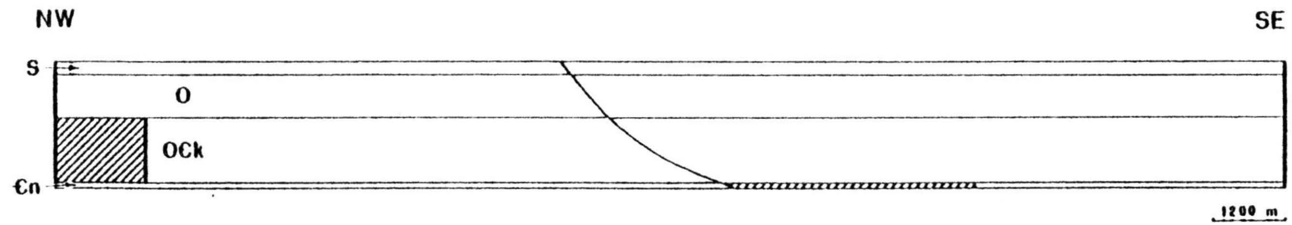
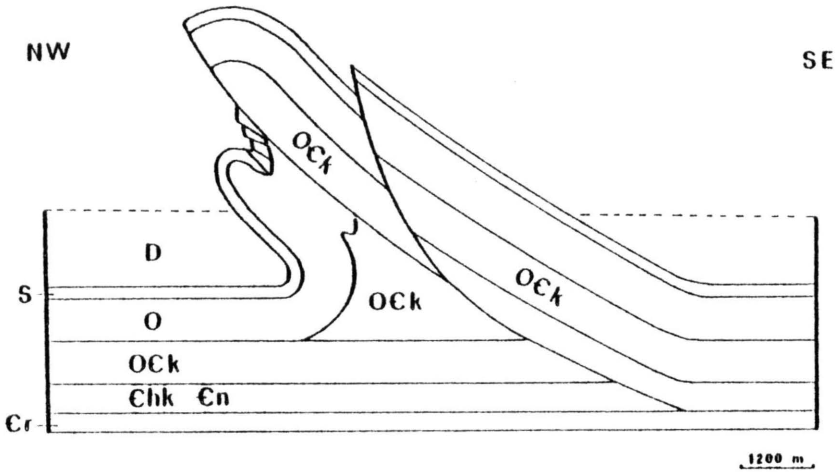
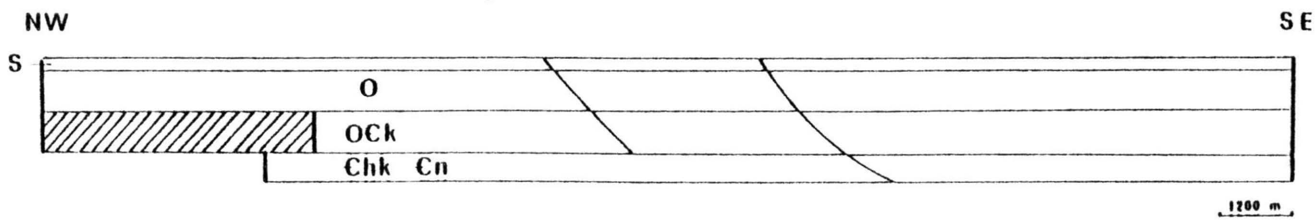

NW
SE
S
O
OЄk
Єn
1200 m

Fig. 9. A balanced model of thrust-fold relationships near the northern terminus of the Saltville thrust, and the restored section. Shaded area represents the amount of Knox necessary to fill the void at the synclinal hinge. The model is based on the following assumptions: 1) detachment occurs in the Nolichucky and Rome, 2) initial faulting originates in the Nolichucky, 3) thickening of the Knox occurs late during deformation by high angle faulting, and 4) Middle and Upper Ordovician strata (excluding the Juniata Fm.) may be treated as a single unit. Symbols same as in Fig. 8.


NW
SE
OЄk
OЄk
D
S
OЄk
O
OЄk
Єhk Єn
Єr
1200 m

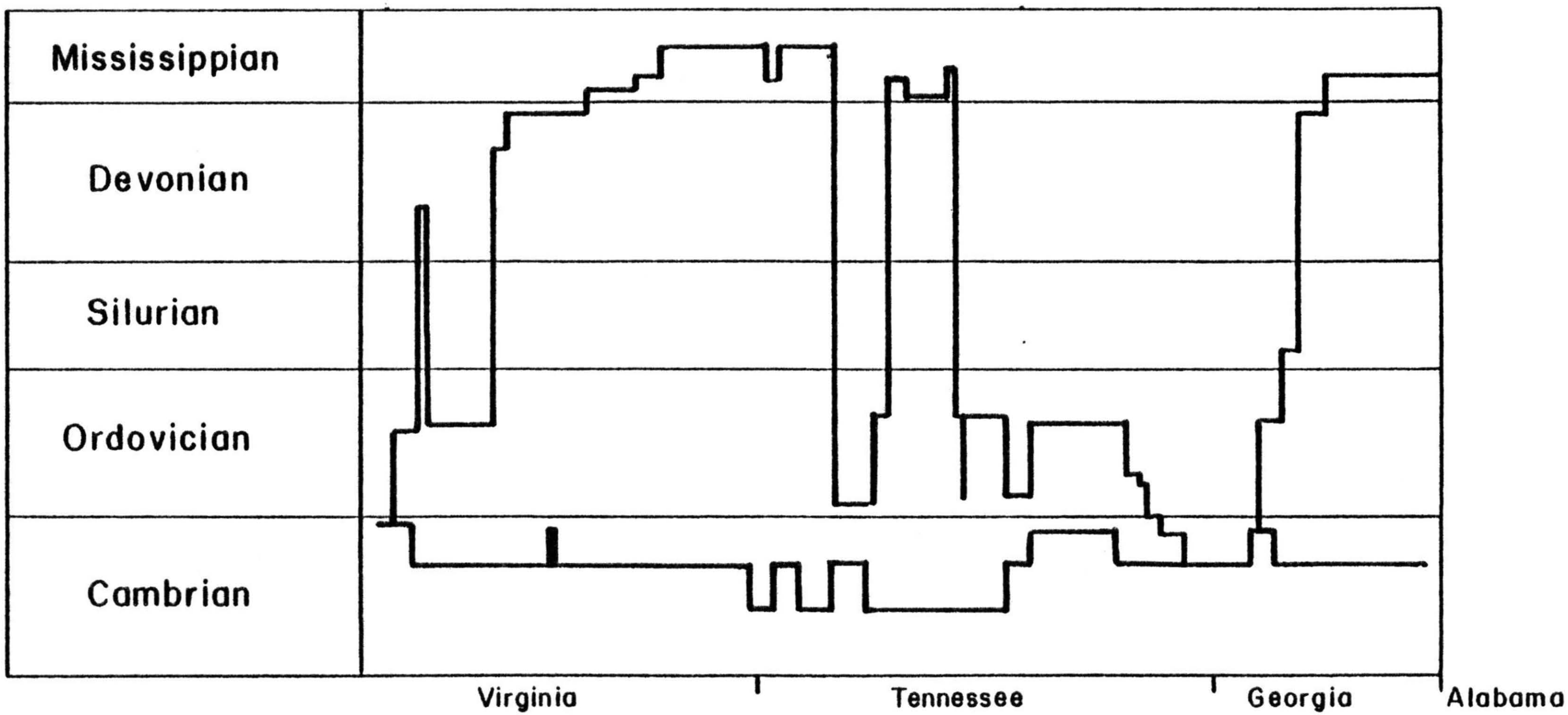

NW
SE
S
O
OЄk
Єhk Єn
1200 m

sedimentary pile is approximately 4000 meters.

Detachment Zones: Thin-skinned models require detachment or décollement zones at depth. Rome shales are widely accepted as the master decollement horizon in the southern Appalachians. The thin-bedded Nolichucky Formation is a possible secondary decollement zone for the Saltville thrust, as the Knox Group is exposed along the fault in the field area. This indicates detachment occurred at the base of the Knox Group, above the Rome-Honaker contact. Recognition of décollement zones from stratigraphic relationships along the Saltville thrust (Fig. 10) also indicate detachment within the Nolichucky Formation. Flat portions on the hanging wall curve (Fig. 10) represent décollement horizons or units directly overlying such horizons (cf. Elliott, 1980). Lithologies corresponding to flat portions of the curve are the Rome Formation, Honaker Dolomite, and Upper Cambrian Copper Ridge Formation. This identifies the Rome as a primary decollement horizon with a minor detachment zone in the Nolichucky, or its equivalents.

Folded and Faulted Zones: The abnormally thick section of Knox Group dolomite exposed in the Sinking Creek anticline is either due to 1) high angle reverse faulting late in the deformation, or 2) thickening of the Knox Group at depth early in the deformation. Repe-

Fig. 10. Stratigraphic displacement along the Saltville thrust. Lower curve represents hanging wall lithologies.


Mississippian
Devonian
Silurian
Ordovician
Cambrian
Virginia
Tennessee
Georgia
Alabama

tition of the lower Knox Group by faulting is implied from the homoclinal dip of bedding, the upright facing, and the lack of folds. Poor exposure has precluded delineation of fault traces.

Footwall block considerations exercised a primary control on the geometry of the balanced section. Bedding plane dips increase to the northwest, away from the thrust, indicating surface lithologies are affected by the curvature of the anticline. This requires that folding of the footwall block begins at present-day ground elevation. No such controls exist for the hanging wall block. The thrust is known to offset Silurian strata at the nose of the Sinking Creek anticline, and probably offsets them farther southwest. No upper limit on displacement can be established except for the general consideration that fold closure occurs 16 km to the northeast.

Folding of Ordovician and Silurian strata creates a void at the synclinal hinge (Figs. 8 & 9). Space created by the void corresponds to the amount of Knox and Nolichucky needed to balance the section. Thus, it is suggested that the space is filled with both Knox Dolomite derived from the ramp, and sections of Nolichucky transported during thrusting. Possible mechanisms for filling the space are: 1) imbrication of the Knox

Group to form a duplex structure, and 2) transporting large blocks of dolomite up and over the ramp (cf. Perry, 1978; Fig 5).

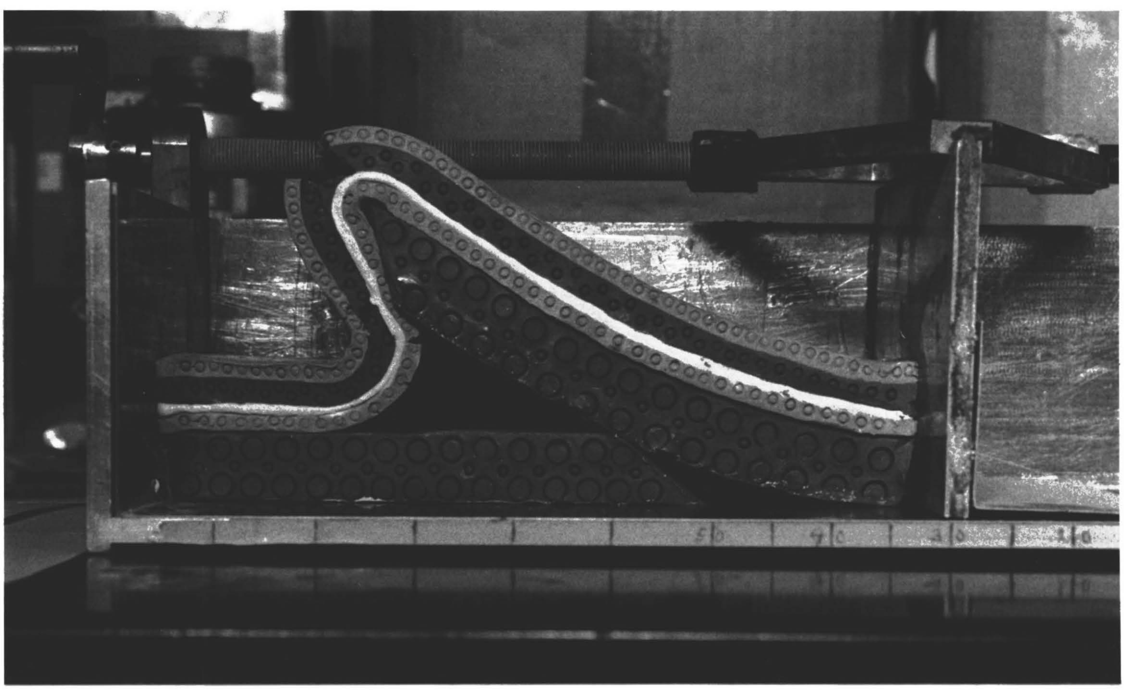
Laboratory models: Thrusting models which have been presented (Figs. 8 & 9) have analogues in laboratory models. Plasticene and putty models (Fig. 11) were deformed in a 43 cm compression box. The basal plasticene unit of the layered sequence was abnormally thick and had a precut 30 degree ramp. The ramp and the base of the hanging wall block were lubricated with petroleum jelly. Compression produced an asymmetric overturned fold. The overturned limb showed high strains, whereas the upright limb was relatively undeformed (Fig. 11). The fold was produced by thrusting at depth and a void is present at the synclinal hinge. Fold asymmetry in the model, with low strains on the upright limb and high strains on the overturned limb, is analogous to deformation across the Sinking Creek anticline.

DEFORMATION HISTORY

Structural relationships and thrust-fold geometries establish a deformation chronology for the northern terminus of the Saltville thrust. Repetition of lower portions of the Knox Group (Fig. 3) is evidence of thickening within the unit. Upward movement of Knox

Fig. 11. Plasticene and putty model deformed in a compression box. a - undeformed strata b - deformation at 25 percent shortening

a.



b.

began as a shear thrust (Willis, 1894) which originated along a décollement in the Nolichucky. The shear thrust cut Knox Dolomite and resulted in an upwarping of higher parts of the sedimentary pile to form an anticlinal fold. Increasing displacement along the thrust caused contemporaneous faulting and folding of the overlying strata to produce a northwest facing, overturned structure. This sequence implies that the thrust originated as a shear thrust, but acted as a break thrust during subsequent deformation.

Second order folding, minor contraction faulting, and cleavage development occurred during later stages of thrusting as the northwest limb of the anticline was being overturned. Deformation in the footwall block also caused thickening in the Martinsburg Formation by folding. Weak contractional deformation post-dated second order folding and caused third order folds to develop. Extensional faulting due to a release of compressive stress was the final deformation stage.

CONCLUSIONS

Mesoscopic fabrics can be used to establish styles of thrust propagation and modes of deformation for regional thrust-sheets. Fabrics show strain patterns due to internal distortions developed during thrusting and folding of a sedimentary wedge. Deformation fabrics developed at thrust terminations reflect styles of thrust propagation and operative displacement transfer mechanisms. Little detailed information exists on such fabrics in the southern Appalachians.

Thrust traces at the northern end of the southern Appalachians commonly terminate in anticlines, indicating that displacement transfer occurs through a thrust to fold transition. The role of fault to fault displacement transfer cannot be evaluated from surface data, since faulting in the central Appalachians is subsurface.

Megascopic deformation mechanisms at the northern terminus of the Saltville thrust are contractional faulting and cylindrical to conical folding. Cylindrical folding predominates except at the nose of the Sinking Creek anticline, where the plunge steepens to 30 degrees. Changes in plunge from subhorizontal to 30 degrees are due to a rapid loss of displacement along the thrust surface at its northern end. Model analogues to these relationships are presented by Gardner and Spang (1973).

Variations in deformation intensity across folds may be used to understand the development of regional structures. Mesoscopic fabrics reflect such variations. Buckle folding with early layer-parallel shortening should produce penetrative fabrics in incompetent units across entire folds. Passive folding, from faulting at depth (cf. Rich, 1934; Harris and Milici, 1977), will produce penetrative fabrics in incompetent units if layer-parallel shortening precedes faulting. This folding alone will not produce penetrative fabrics on the back-limbs of folds.

Strain patterns in the Sinking Creek anticline show that the regional folding was passive. Mesoscopic strain accommodation by folding, faulting, and cleavage development caused a tectonic thickening of Middle and Upper Ordovician rocks on the northwest limb of the anticline. Mudrocks on the southeast limb have no penetrative fabric. Elsewhere at the northern end of the southern Appalachians, Moccasin mudrocks have been shown to readily accommodate strain due to layer-parallel shortening (Simon, 1981). These strain patterns, along with supporting field data, suggest that thrust propagation at the northern terminus of the Saltville thrust occurred through an early stage of shear thrusting at depth, which passively folded the upper sedimentary pile. Subsequent movement caused the thrust to act as a break thrust and cut through folded strata.

The propagation of regional thrusts from areas where fold axes converge is not indicated by map patterns. Where these relationships are documented

(Canadian Rocky Mountains; Ollerenshaw, 1968), folding is on a smaller scale than in the southern Appalachians. Perhaps such processes are scale-dependent.

Geologic interpretations of regional structures must be consistent with mesoscopic deformation patterns observed in the field. Deformation fabrics in the southern Appalachians require further study in order to evaluate and refine existing models of thrust and fold development.

FAULT ROCK FABRICS ALONG THE SALTVILLE THRUST: IMPLICATIONS FOR THRUST-SHEET EMPLACEMENT

INTRODUCTION

Concern about mechanisms by which thrust sheets move large distances (Smoluchowski, 1909; Hubbert and Rubey, 1959; Wilson, 1970; Brock and Engelder, 1977; Chapman, 1979) has been associated with the development of thin-skinned tectonic models in foreland fold zones. This problem is pertinent with regard to the allochthonous character of the Blue Ridge and Piedmont of the southern and central Appalachians (Cook et al, 1980; Harris and Bayer, 1979). Hypotheses proposed to overcome frictional resistance at the base of a thrust-sheet include abnormally high pore pressures to reduce the effective normal stress (Hubbert and Rubey, 1959), movement and flow in materials of low shear strength such as shale, coal, and evaporites (Wilson, 1970), and movement on a zone sheared by pervasive cataclasis (Brock and Engelder, 1977).

One approach to this problem is to determine physical mechanisms of rock deformation both along and adjacent to the fault zone. Friction-dominated mechanisms involve cataclasis, that is brittle fracture accompanied by rigid body rotation, frictional grain-boundary sliding, and dilatancy (Engelder, 1974; Sibson, 1977), and frictional sliding along existing planes. Field studies of fault surfaces and fault rocks along major thrusts will provide information on the mode of thrust-sheet emplacement and the approximate physical conditions during emplacement (cf. Sibson, 1974; Elliott, 1976; Brock and Engelder, 1977).

Fault gouge formation through cataclastic deformation has been examined in the field and laboratory. Laboratory investigations using precut blocks of sandstone separated by various thicknesses and types of prepared gouge, have demonstrated the relationships between gouge characteristics, deformation intensity, and mode of movement along fault surfaces (Engelder, 1974; Engelder et al., 1975). Field studies in Nevada (Brock and Engelder, 1977) on cataclastic deformation associated with the Muddy Mountain overthrust related the fault-rock fabrics to sliding mechanisms. Fault-rock fabrics and physical parameters of faulting in a quartzo-feldspathic medium have been defined for the elastico-frictional and quasi-plastic regimes (Sibson, 1977). Other investigations have established relationships between friction-dependent deformation mechanisms and resulting rock fabrics by using both theoretical and empirical methods

(Borg et al., 1960; Stearns, 1968; Donath and Fruth, 1971; Jackson and Dunn, 1974; Elliott, 1976).

Much work on friction-dependent deformation has focused on laboratory investigations. Relationships between fault-rock fabrics and deformation mechanisms are still poorly understood in natural fault zones. This paper provides mesoscopic and microscopic data demonstrating relationships between fault-rock fabrics, deformation mechanisms, sliding mechanisms, and physical conditions during emplacement of the Saltville thrust-sheet. This thrust, one of the regional thrusts of the southern Appalachians, has a strike-length of 690 km and extends from southwestern Virginia to northern Alabama (Fig. 1). The study was confined to three outcrops along the northern portion of the thrust in southwestern Virginia (Fig. 2). The fault zone, fault-rock characteristics, deformation intensity, and their interrelationships are described in order to understand: 1) progressive cataclasis and gouge formation in dolomites, 2) the evolution of fault-rock microfabric, 3) operative deformation mechanisms during thrust-sheet emplacement, 4) physical conditions during thrust-sheet emplacement, and 5) sliding mechanisms. The study should be applicable to faulting and deformation mechanisms associated with low temperature and pressure conditions of the elastico-

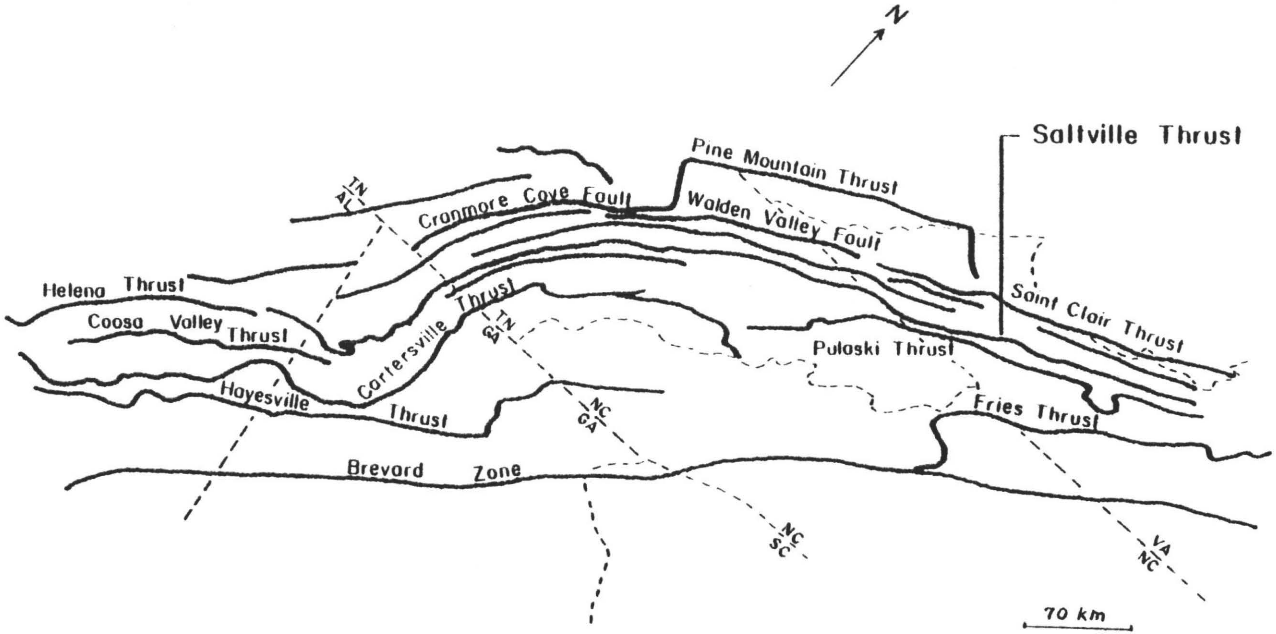


Fig. 1. Map showing the major overthrusts of the southern Appalachians.

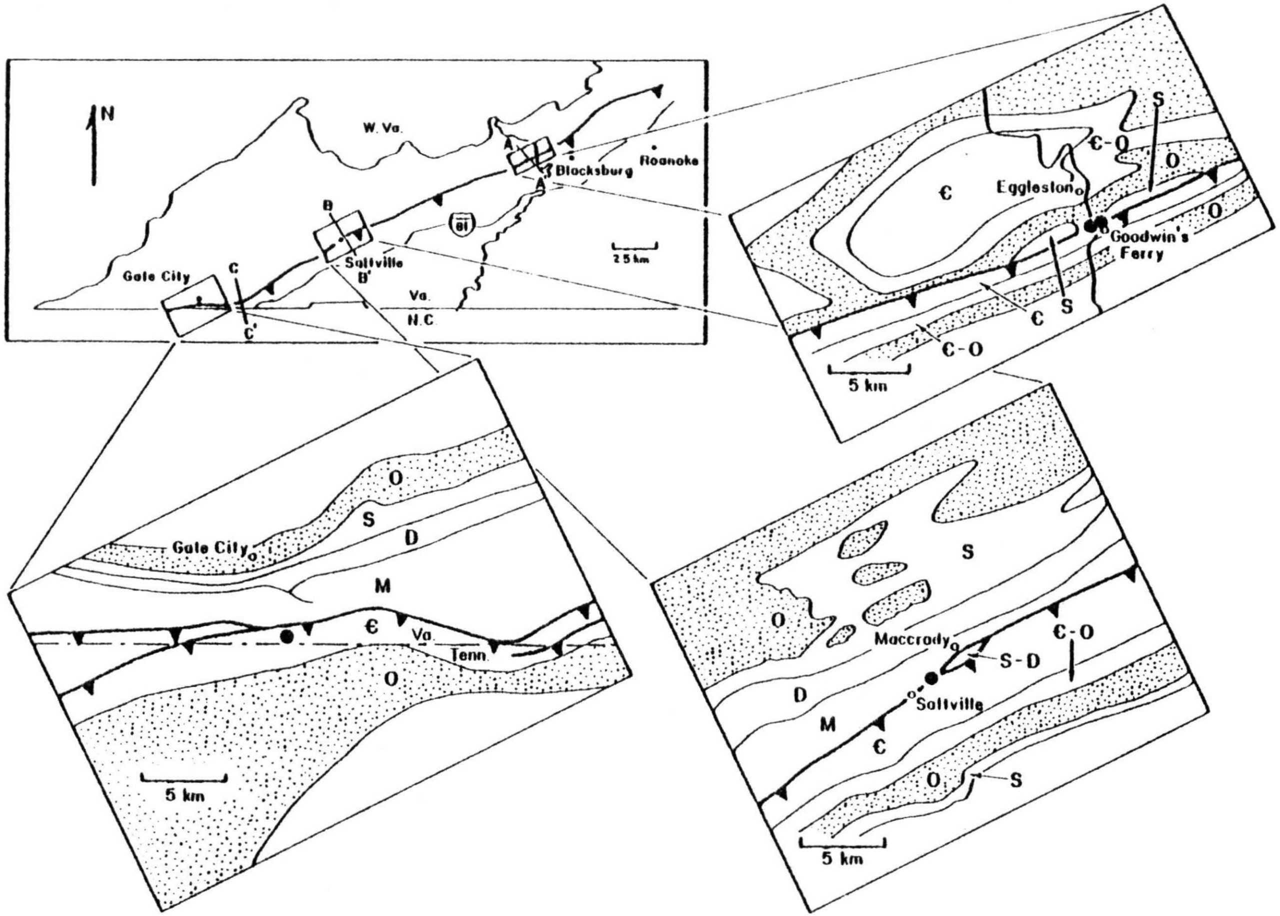


Fig. 2. Index map showing sample locations along the Saltville thrust. Inserts give local geologic relatioships. (•) - Sample location; C - Cambrian, O - Ordovician, S - Silurian, D - Devonian, M - Mississippian.

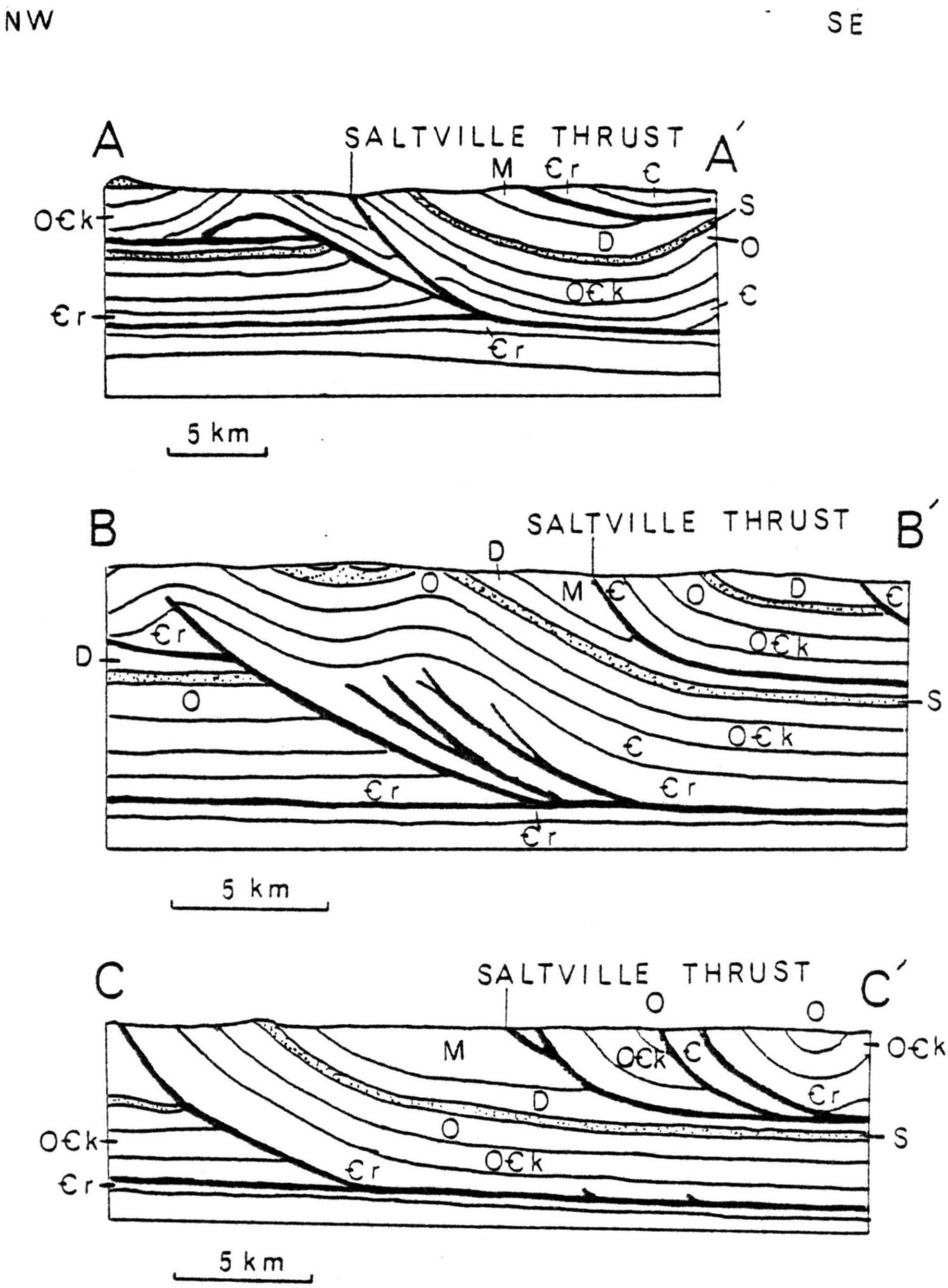


Fig. 3. Cross sections from sample locations. Lines given on index map (Fig. 2) (A - A´, after Milici, 1970; B - B´, after Milici, 1980)

frictional regime.

FAULT-ROCK CLASSIFICATION

Recent literature describing fault-rock fabrics does not provide a uniform classification of such fabrics. This is true of the term "gouge", which is used in the genetic sense for a fabric formed between two sliding surfaces (cf. Engelder, 1974), and in a descriptive sense for an incohesive fabric with greater than 30 percent matrix (Sibson, 1977). Sibson's (1977) classification will be used in this paper to describe fault-rock fabrics generated in the elastico-frictional regime (Fig. 4). The one modification proposed is the use of the prefix term "foliated". The original classification precluded the existence of foliated cataclasites, which are now recognized and described in this paper.

MESOSCOPIC ASPECTS OF THE SALTVILLE THRUST

The Saltville thrust in Virginia and Tennessee is characterized by variations in the dip of the fault surface: 10 - 30 degrees in Tennessee (Haney, 1966); 0 - 30 degrees at Saltville, Virginia (Muangnoicharoen, 1978, figure 5-A); 50 degrees at Goodwins Ferry, Virginia; and 30 degrees in Tennessee and Virginia (Rodgers, 1970).

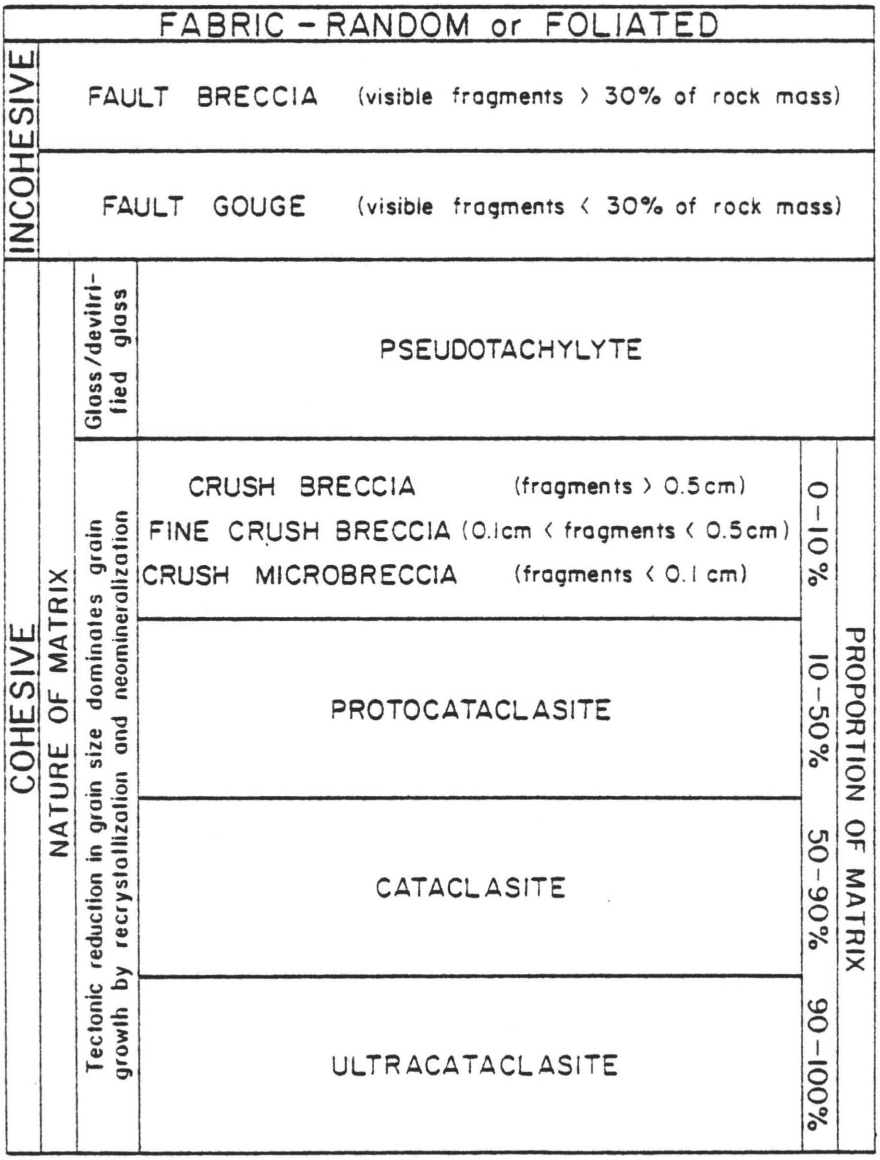


Fig. 4. Fault rock classification for deformation in the elastico-frictional regime (modified after Sibson, 1977).

In general, the Saltville thrust has moderate to steep dips along its northern trace. Rocks along the fault surface are cohesive but less competent than surrounding rocks. Cataclasites, where developed, are not always separated from surrounding lithologies by discrete surfaces. In some areas a zonation is evident, whereas in other areas the contact is gradational. Cataclasite and ultracataclasite zones are 0.25 meters to 3 or 4 meters wide. Thick or massive brecciated zones are absent. Deformation intensity, evidenced by fracturing and minor shearing, decreases rapidly away from the fault zone (Fig. 5). Hanging wall dolomites are more fractured than limestones or shales of the footwall block. A fractured zone generally occurs above the fault surface (Figs. 6 & 8). Fault zone characteristics are presented below:

Goodwins Ferry, Virginia: Cambrian Honaker dolomites are thrust over Ordovician limestones and shales of the Martinsburg Formation. The fault surface dips 50 degrees southeast. A thin zone of cataclasites ranges in width from 0.30 to 0.75 meters. The cataclasites are restricted to the dolomites of the hanging wall block.

Saltville, Virginia: Cambrian Honaker dolomites are thrust over Mississippian limestones of the Greendale syncline (Figs. 2 & 3), but the fault surface is poorly exposed. A zone of cataclasites and ultracataclasites 3 meters thick occurs in the fault zone, along with an unidentified block of sandstone (Fig. 7). Deformation in the dolomites above the fault zone is restricted to minor fracturing.

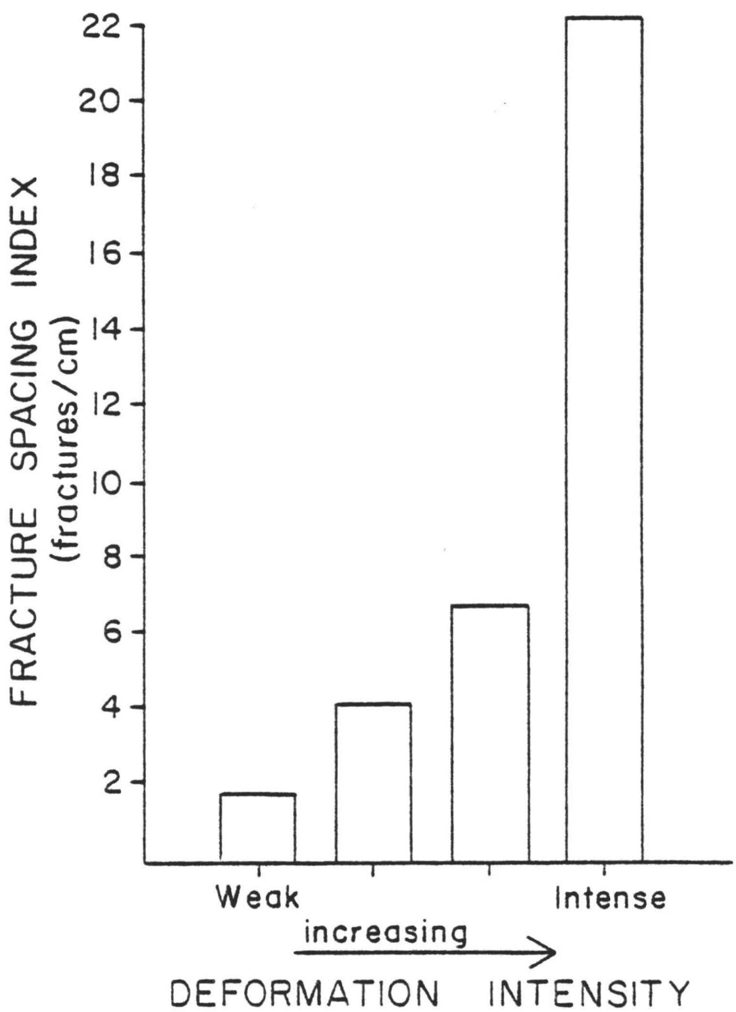
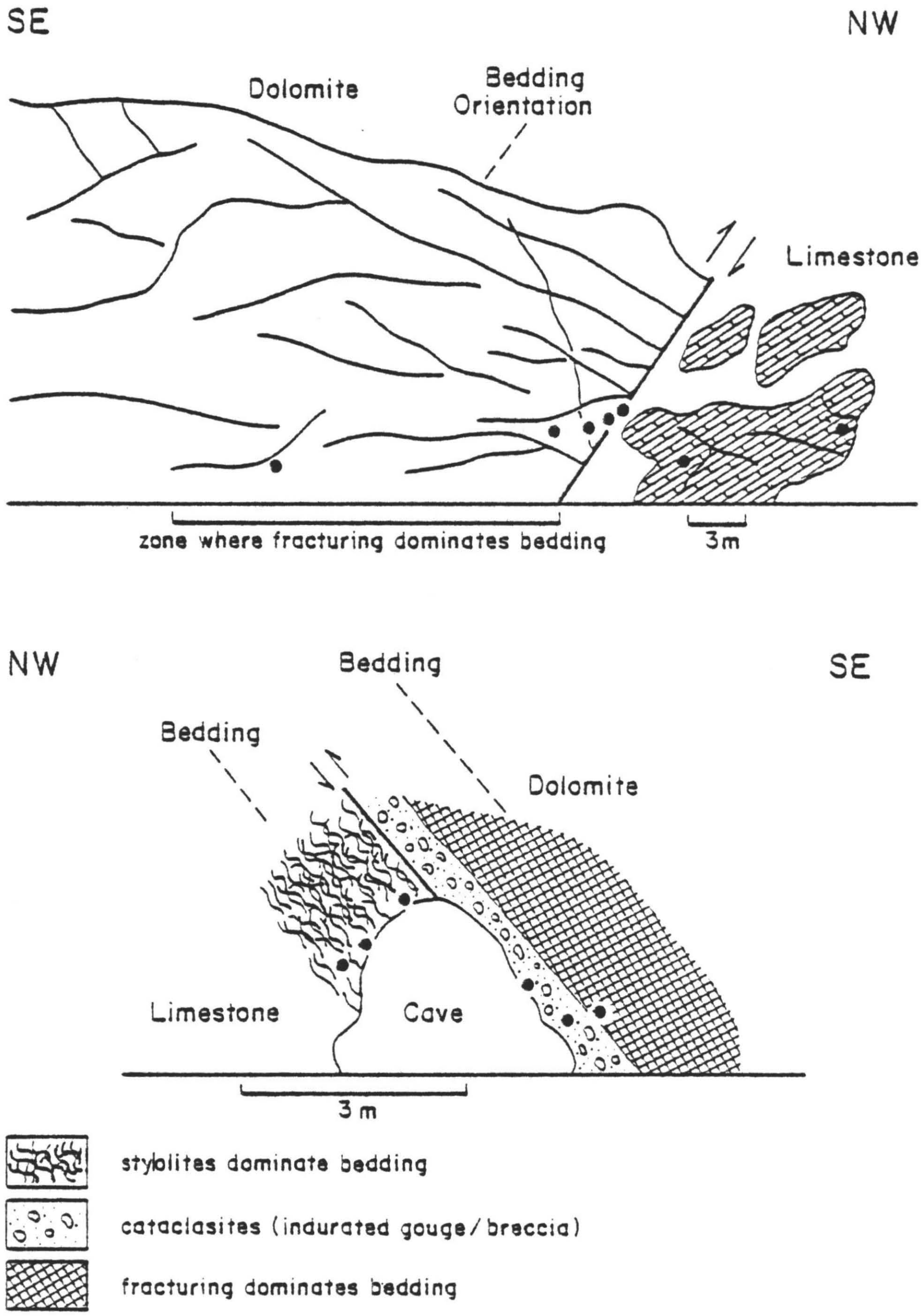


Fig. 5. Fracture spacing versus deformation intensity in dolomites. Deformation intensity increases towards the fault surface.

Fig. 6. Fault exposures at Goodwins Ferry, Virginia. (•) - Sample locations; south side of river (above), north side of river (below).


SE
NW
Dolomite
Bedding Orientation
Limestone
zone where fracturing dominates bedding
3m
NW
SE
Bedding
Bedding
Dolomite
Limestone
Cave
3 m
stylolites dominate bedding
cataclasites (indurated gouge/breccia)
fracturing dominates bedding

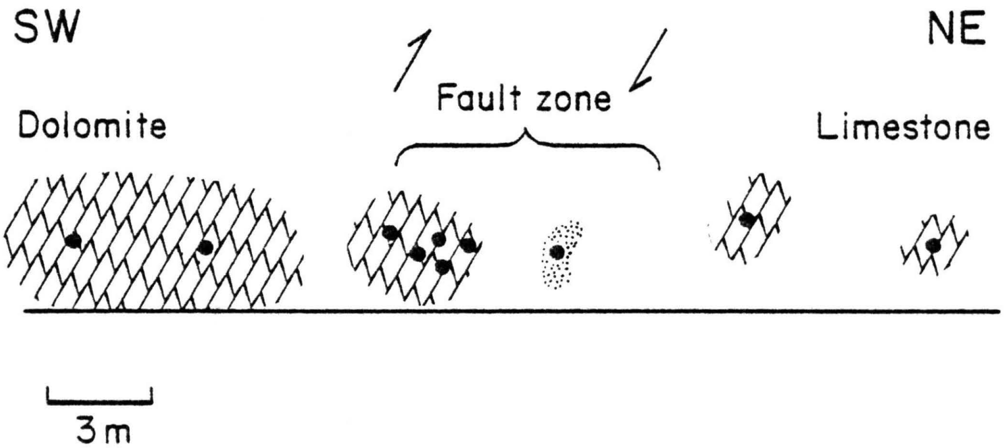


Fig. 7. Fault exposure at Saltville, Virginia. (•) - Sample locations.

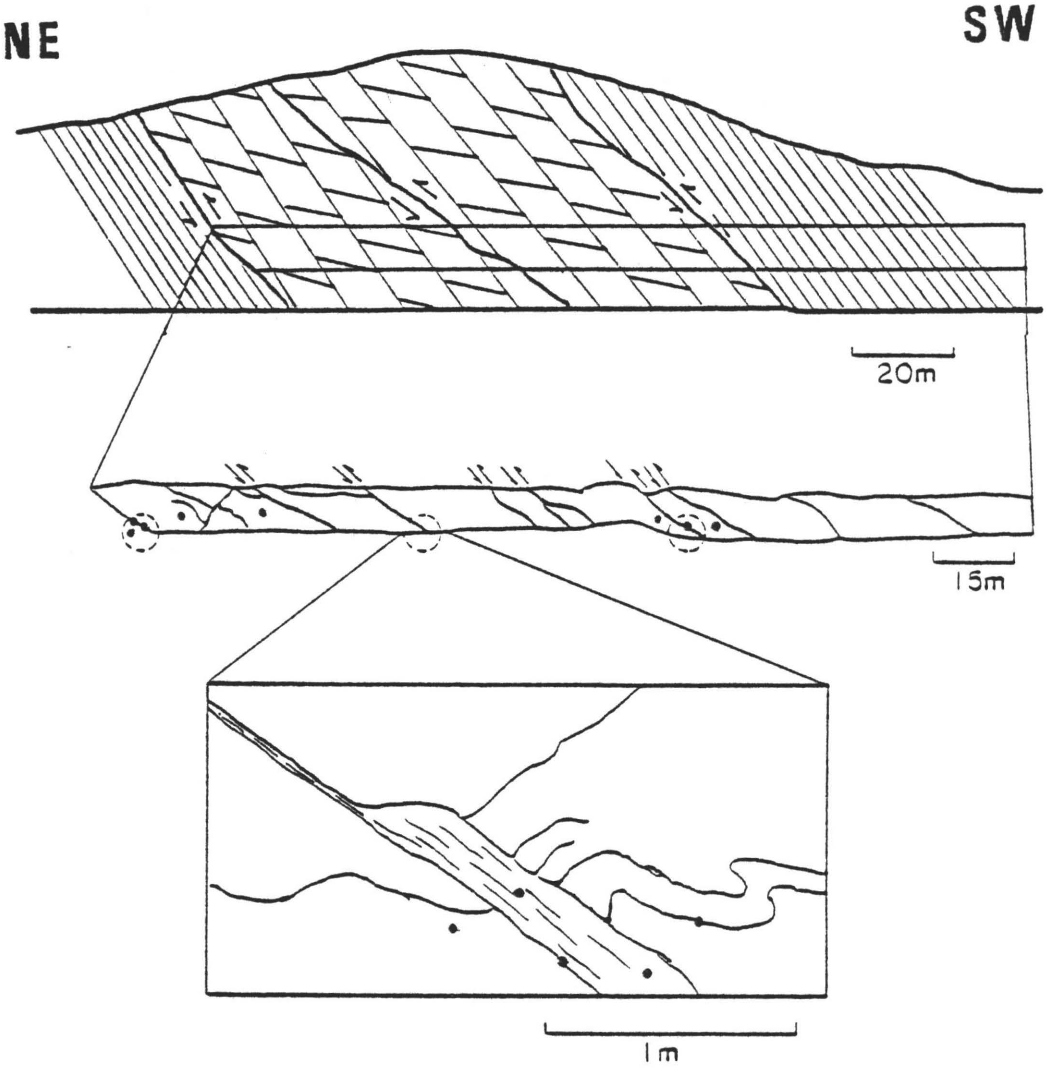


Fig. 8. Fault exposure at Gate City, Virginia.
(•) - Sample locations.

Gate City, Virginia: The fault is a backsplay of the Saltville thrust and places a horse of dolomite over Cambrian Rome shales (Fig. 8). The fault surface has a dip of 50 degrees southeast. The development of cataclasites is restricted to a narrow zone (0.3 meters wide) at the dolomite-shale interface. Minor fracturing occurs in the dolomites away from the fault surface.

CATACLASTIC DEFORMATION OF DOLOMITES

Development of cataclastic fabrics in dolomites along the Saltville thrust has been divided into four stages (Fig. 9). Stages are defined by bulk deformation characteristics.

Stage I Fabrics: These include relatively undeformed dolomites characterized by the development of widely spaced (0.5 cm - 1.0 cm) microfractures and microshears (plate 1a). Microshears are distinguished from microfractures by detectable shear movement. Fault-rocks are crush breccias with less than 5 percent matrix (grains less than 10 μm in diameter). Fractures and shears occur both as single surfaces and in zones. The zones result from the coalescing of numerous fracture and shear surfaces. Single fracture surfaces commonly form en echelon patterns. The fractures at this stage intersect one another at angles of approximately 60 degrees (Fig. 10).

Stage II Fabrics: Original microfractures are now shear zones with widths up to several mm (plate 1b).

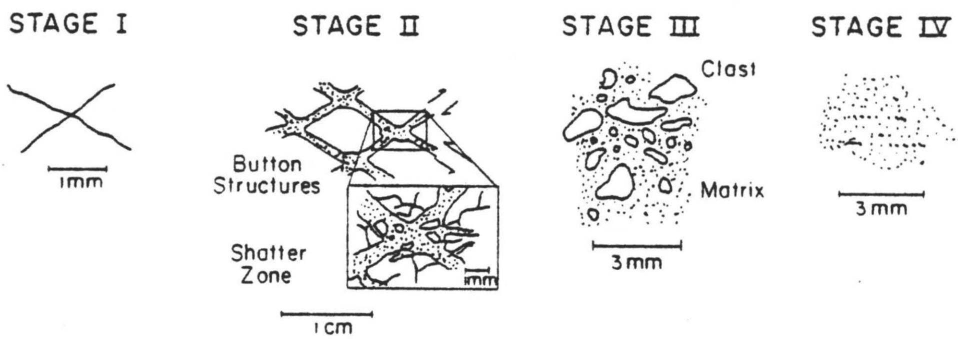


Fig. 9. Schematic representation of cataclastic deformation in dolomites. Stage IV corresponds to the most intensely deformed fault rock fabric.

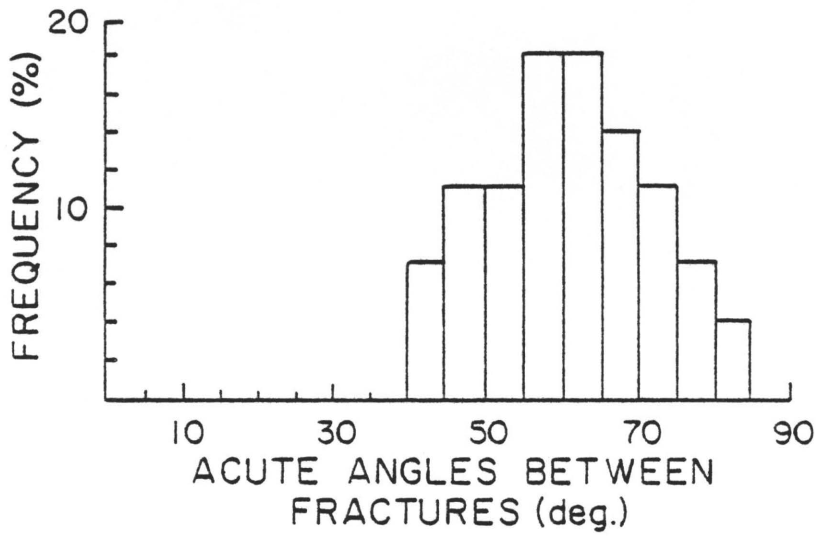


Fig. 10. Acute angles between fractures versus their frequency of occurrence in relatively undeformed dolomites (stage I deformation).

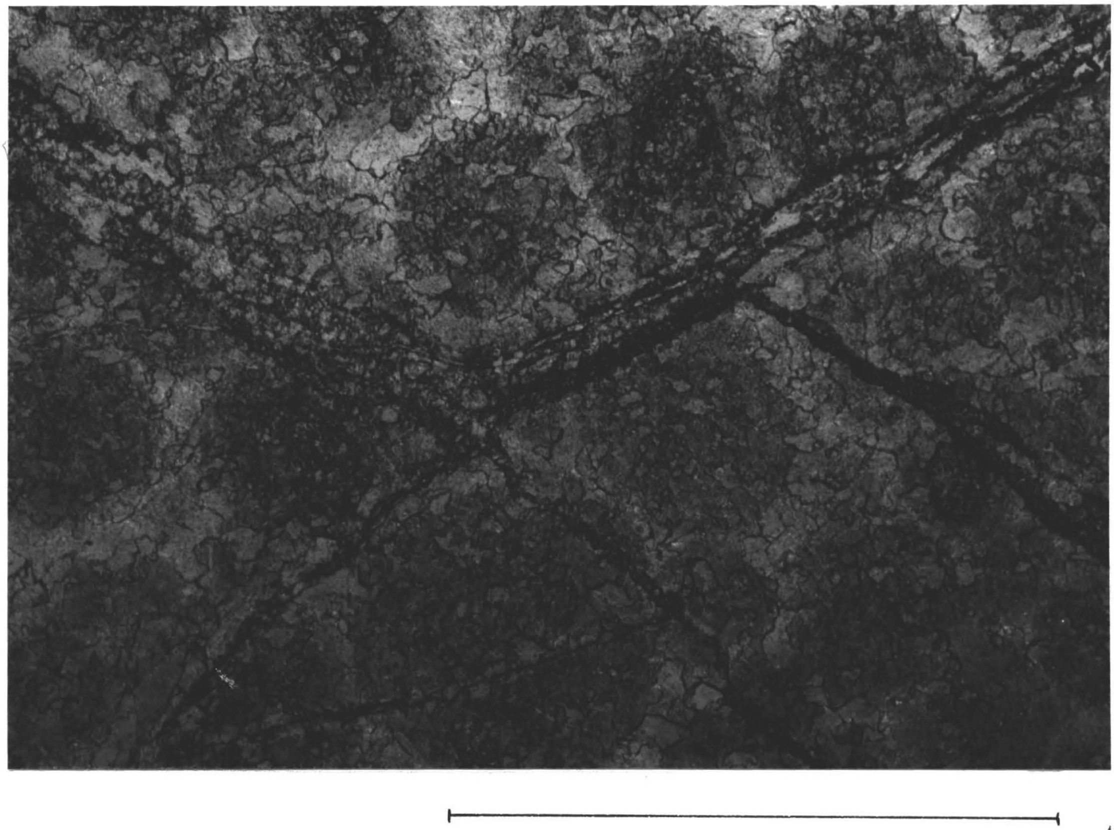


Plate 1a. Stage I deformation - microfracturing of original fabric. (Bar scale - 2 mm)

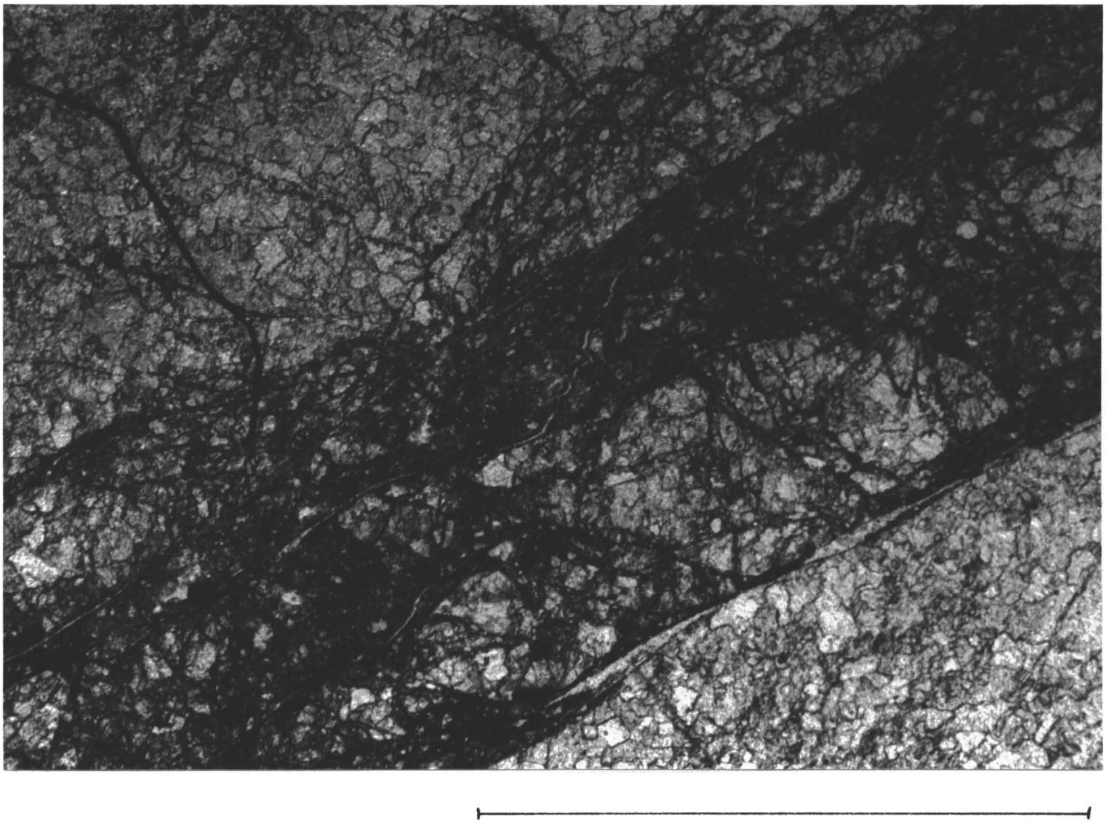


Plate 1b. Stage II deformation - formation of microshears. (Bar scale - 2 mm)

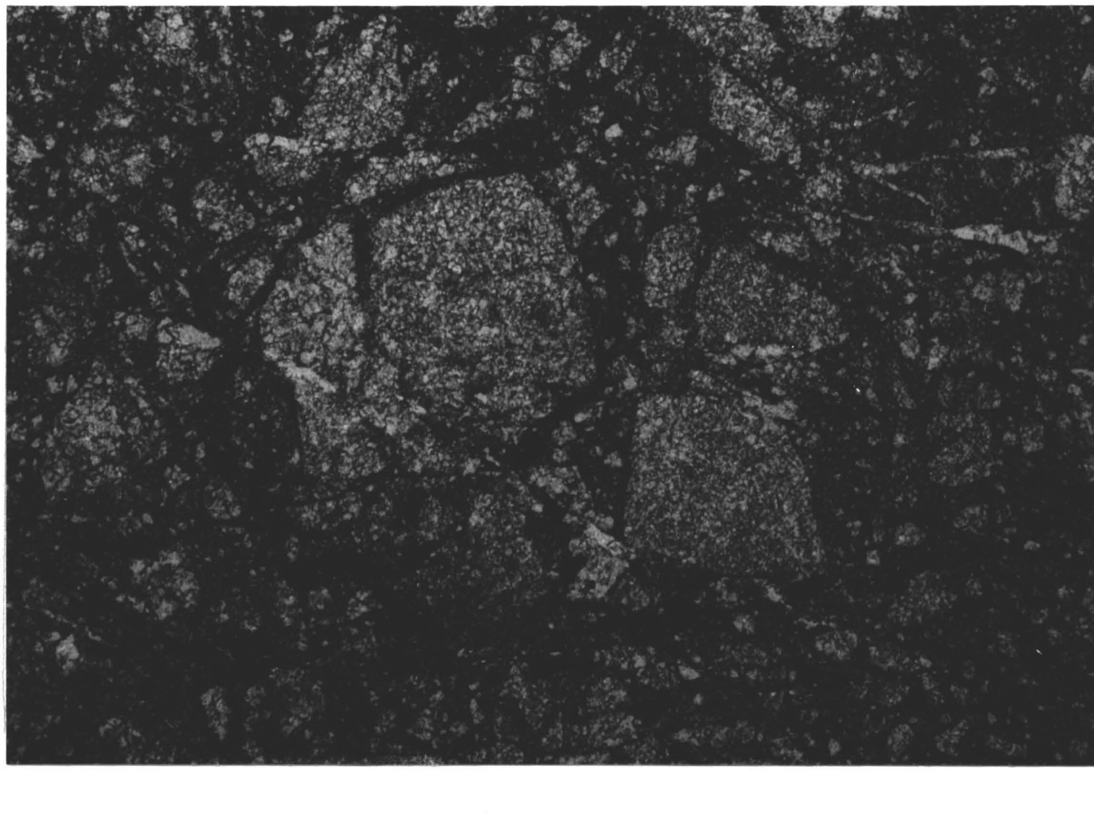


Plate 1c. Stage III deformation - complete disruption of original bulk fabric. (Bar scale- 2 mm)

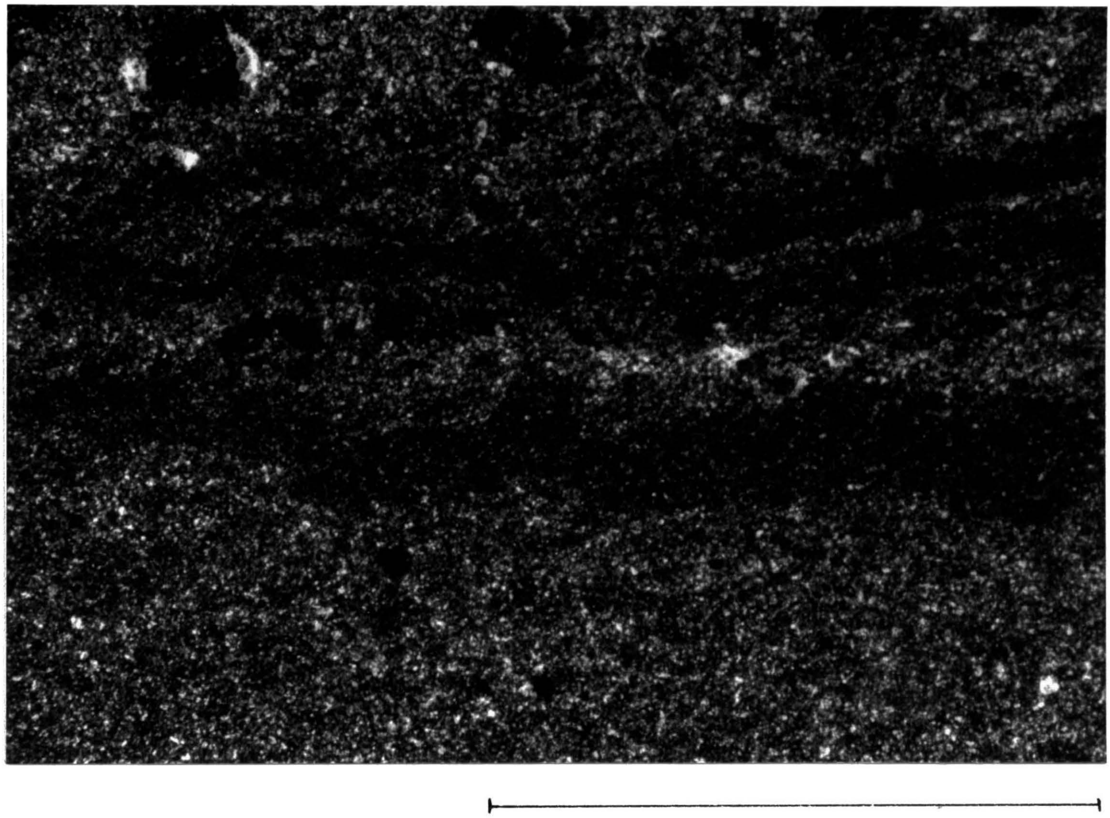


Plate 1d. Stage IV deformation. (Bar scale - 2 mm)

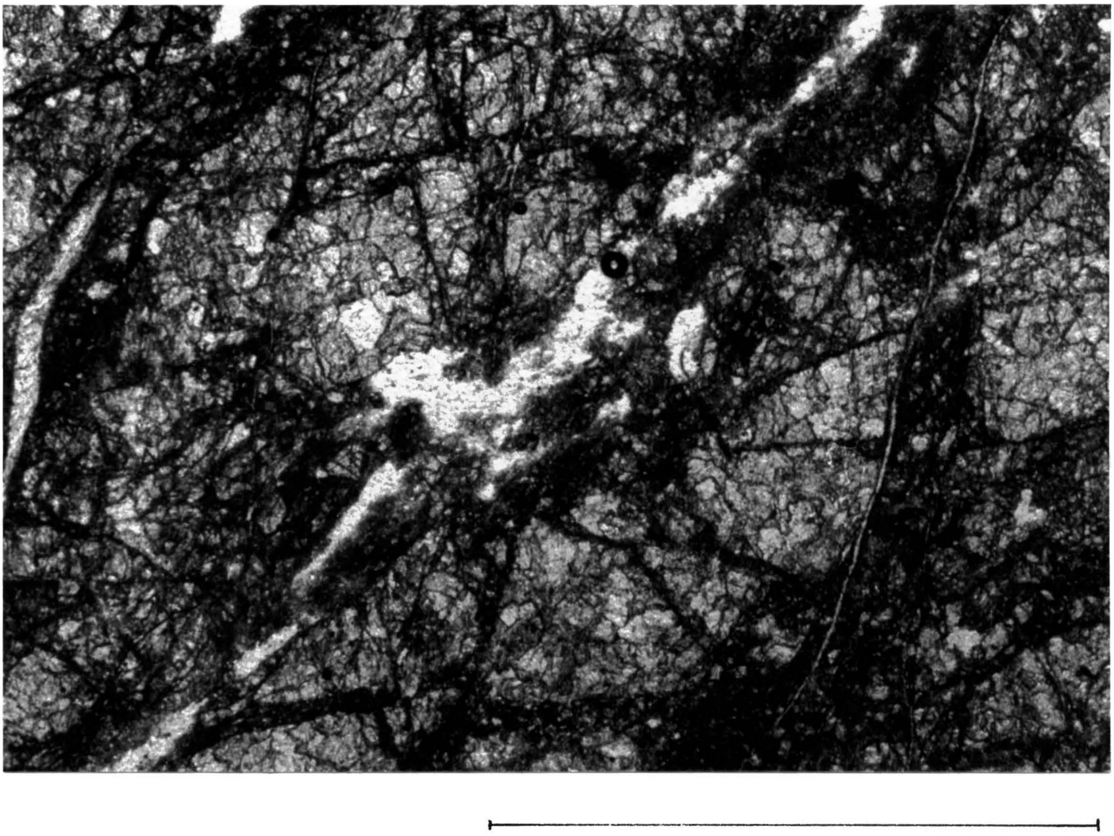


Plate 2. Shatter zone developed in a stage II fabric. (Bar scale - 2 mm)

Cataclasites with 50 percent matrix occur in the shear zones, however, the bulk fabric is a protocataclasite. On mesoscopic and microscopic scales, intersections of major shears are "shatter zones" of intense fracturing (plate 2). Button structures (diamond-shaped pods of relatively undeformed dolomite) occur between sets of intersecting shear surfaces (Fig. 9).

Stage III Fabrics: Original bulk fabric has been completely disrupted and button structures are not recognizable in the fault-rock fabric (plate 1c). Cataclasites have 50 to 60 percent matrix and clasts are 10μm to several mm in diameter (most are between 10 and 100μm).

Stage IV Fabrics: Fault-rocks are ultracataclasites with 99 percent matrix (plate 1d). Individual grains are rounded to rhombohedral and less than 10μm in diameter. The fabric has a uniform texture with color variations which impart a banding or fluxion-type structure to the rock.

FAULT-ROCK CHARACTERISTICS

All fault-rocks are cohesive (indurated) and generally nonfoliated. Fault-rocks which develop during stages II - IV of deformation range from protocataclasites to ultracataclasites, and most are cataclasites having

50 to 70 percent matrix. Clast populations are greater than 70 percent dolomite. Quartz clasts (chert and detrital quartz) from the original dolomite are common in some cataclasites. Limestone clasts are rare. Foliated and nonfoliated cataclasites, and foliated ultracataclasites occur along the fault.

Nonfoliated cataclasites have a random fabric with most clasts ranging from 10 to 100μm in diameter. Clast shapes include rounded, angular, elongate, and rhombohedral. Grain boundaries are smooth to irregular, and sharp. Individual clasts "float" in the matrix. Nonfoliated cataclasites are best developed at Goodwins Ferry, where dolomite is thrust over interbedded limestone and shale, and 90 to 95 percent of the clasts are dolomite, with 5 to 10 percent being chert.

Foliated cataclasites occur where dolomite is thrust over Rome shale (Gate City). The majority of the clasts are 10 - 200μm in length. Individual clasts are elongate and have smooth to embayed, sharp boundaries, which are commonly pressure-solved parallel to long axes. Individual clasts float in the matrix. Approximately 70 percent of the clasts are dolomite and 30 percent are detrital quartz. The dolomite clasts commonly are more elongate than quartz clasts. Foliation types include: 1) preferred orientation of long axes of clasts (Fig. 11),

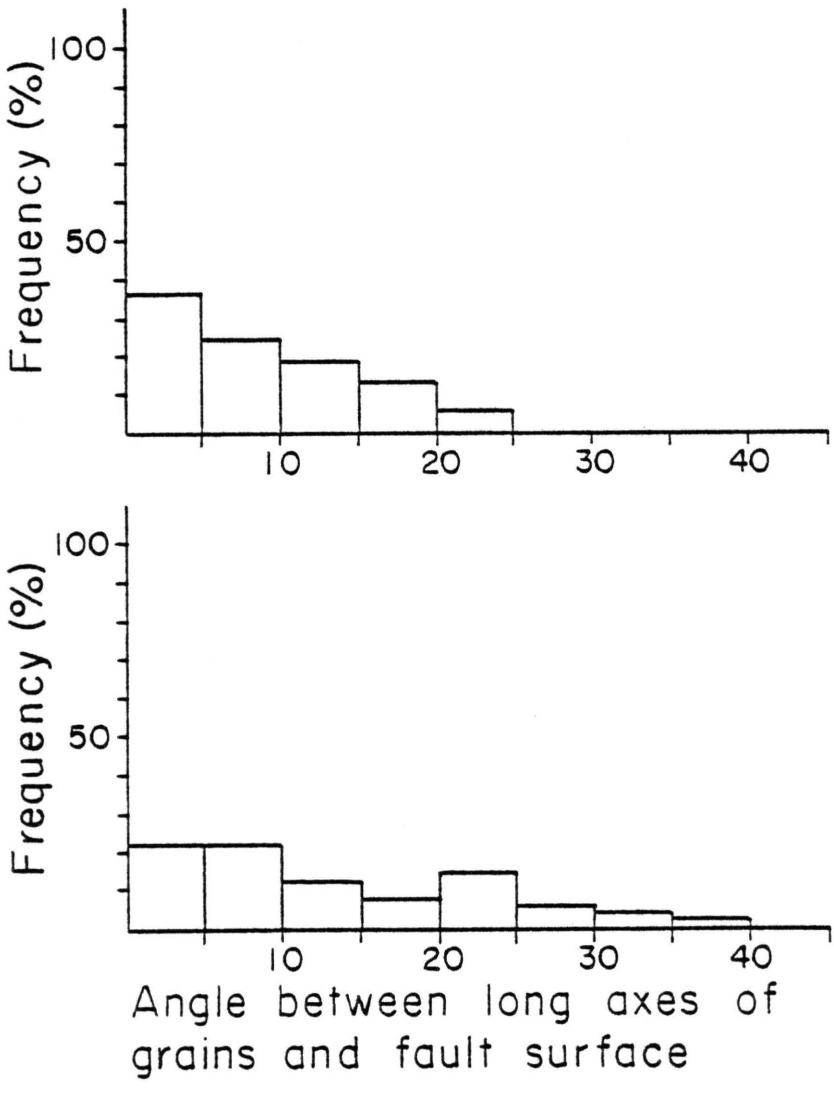


Fig. 11. Angle between long axes of grains and the fault surface versus frequency of occurrence in a foliated cataclasite (Gate City, Va.). Each plot represents 100 measurements and the two plots are from mutually perpendicular sections.

visible on a mesoscopic and microscopic scale, and 2) development of subparallel anastomosing stylolites, visible only on a microscopic scale.

Foliated ultracataclasites have fluxion-type banding (plate 1d) in which individual grains are not visible under a petrographic microscope. Fabrics of ultracataclasites consist of aggregates of rounded to rhombohedral, unoriented dolomite grains (5μm diameter).

FABRIC EVOLUTION

Apart from cataclastic fabrics, other textural elements in the fault zone dolomites include fractures, veins, microshears, and stylolites. Overprinting between these elements defines a consistent deformation chronology in the fault-rocks (Fig. 12). Stage I deformation marks the onset of cataclasis. As shearing increases, minor shear zones develop with gouge fillings (stage II). During early phases of deformation, stages I and II, the bulk fabric produced results in a protocataclasite upon induration. Progressive brittle failure leads to stage III deformation and complete disruption of original fabric. Extensive shearing and rotation of grains takes place. Foliated gouges develop by grain rotation and pressure-solution along grain boundaries. Continued frictional grinding and grain-size reduction produces a

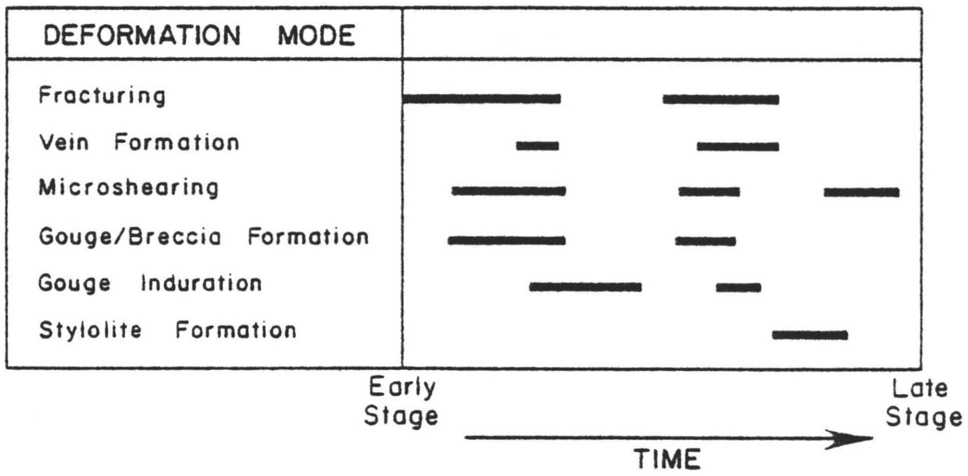


Fig. 12. Plot of deformation modes versus their relative timing in the formation of the fault rock microfabric. The plot represents a compilation of data from all sample locations. The lengths of individual bars do not relate to deformation intensity.

gouge with the matrix composition of an ultracataclasite (stage IV). Differential shearing in the gouge forms fluxion-type banding. The gouges are subsequently indurated to form the cataclasites described previously.

At least two periods of shearing have been recognized on the basis of discrete shear zones in stage III cataclasites (plate 3). Late stage shearing reduces grain-size relative to the original cataclasite (Fig. 13). Prior induration of the first gouge is inferred from the sharp contact between shear zone and host rock. The last stage in the evolution of the fabric was formation of thick stylolite seams (up to 1.0 cm thick) subparallel to the fault surface. These probably developed after locking of the fault. Pressure-solution was due to the weight of superincumbent strata. The late stage of micro-shearing (Fig. 12) was insignificant in that it did not form a gouge.

SIGNIFICANCE OF CATACLASTIC FABRICS

Deformation mechanisms along faults are affected by temperature, fluid pressure, confining pressure, rock type, and velocity mode (Donath and Fruth, 1971; Sibson, 1977). Conditions which favor cataclasis correspond to those in the elastico-frictional regime (cf. Sibson, 1977, p. 200), which is characterized by low temperatures and

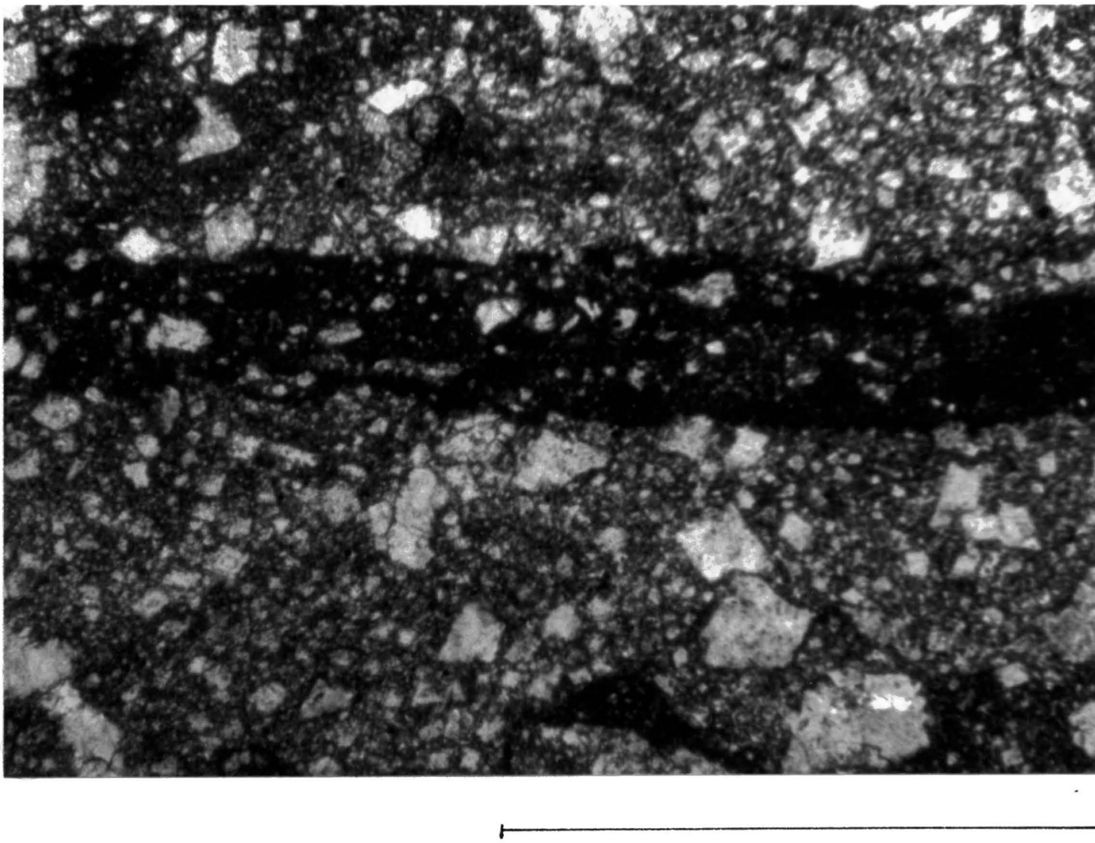


Plate 3. Grain size reduction in a shear zone developed in a cataclasite. (Bar scale - 2 mm)

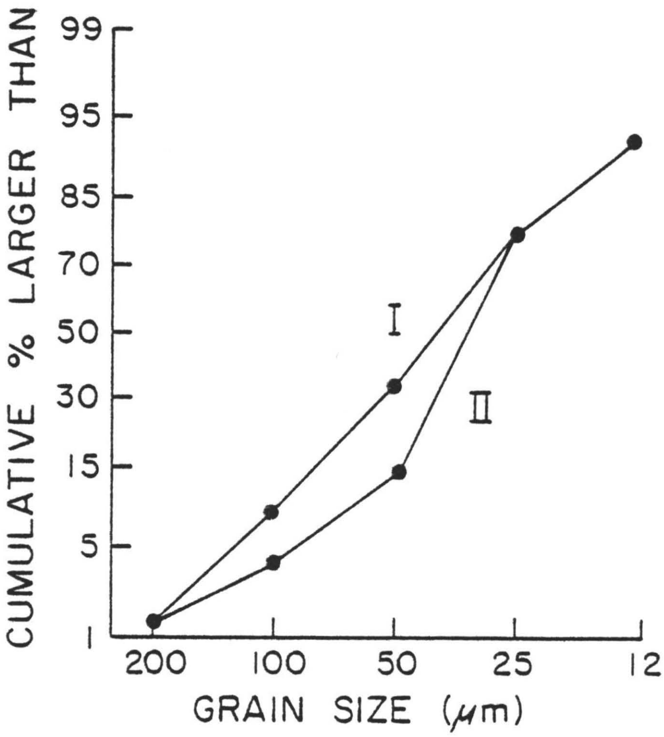


Fig. 13. Cumulative frequency curves for cataclasites from the Goodwins Ferry location. Individual curves are based on 100 apparent long axes; Curve I - original cataclasite, Curve II - secondary cataclasite developed in a shear zone in the original cataclasite.

pressures (i.e. metamorphic grades lower than greenschist facies). Fault-rock fabrics produced during thrust-sheet emplacement in this regime are useful in understanding deformation mechanisms. Laboratory experiments have demonstrated that increasing slip along a sliding surface is accompanied by a decrease in grain-size (Engelder, 1974). The increase in slip represents an increase in deformation intensity in the laboratory experiments. However, other parameters besides slip affect deformation intensity in natural fault-rocks. High pore pressure tends to reduce frictional grinding and decreases deformation intensity in the fault-rocks. Also, flowage in incompetent rock units, perhaps footwall lithologies, accomodates strain and reduces deformation intensity. Grain-size reduction in a natural fault-rock is thus a function of frictional grinding (Fig. 14), and not displacement. Therefore, the transition from cataclasite to ultracataclasite represents an increase in frictional grinding.

Cataclasites contained many mildly fractured dolomite clasts. The abundance of clasts indicates that frictional grinding during sliding was alleviated. Two possibilities arise: 1) sliding was accompanied by high pore pressures, and 2) after initial gouge generation, sliding was accomplished along a discrete surface,

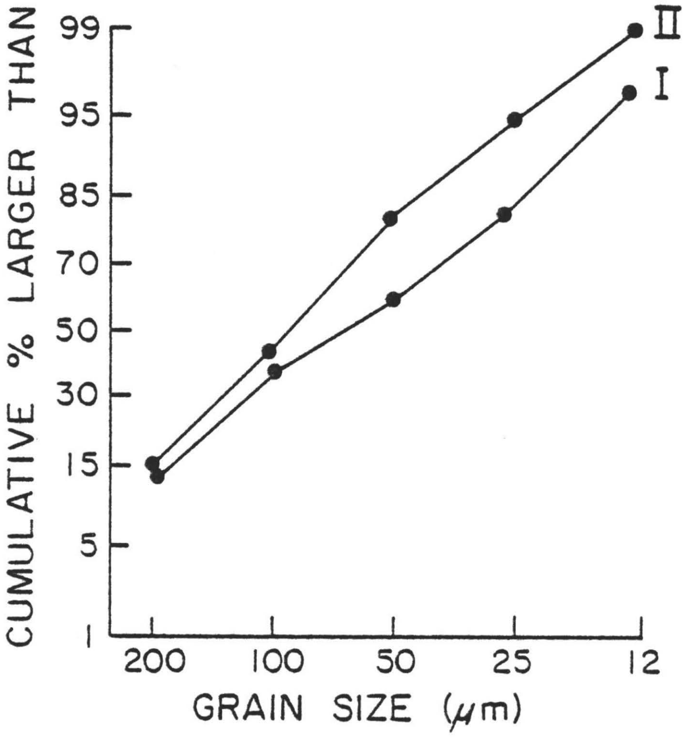


Fig. 14. Cumulative frequency curves for cataclasites from the Gate City location. Individual curves are based on 100 apparent long axes; Curve I - fault rocks from the primary fault where dolomite is thrust over shale, Curve II - fault-rocks from a secondary fault to the southwest.

possibly the gouge-rock interface (cf. Engelder et al., 1975). Seismic failure is implied in both cases. The significance of clast-preferred orientation in foliated cataclasites is unclear. It is possible that such fabrics form in response to slow slip rates. High slip rates indicate rapid dissipation of energy which should lead to a rapid increase in local entropy and disordering of the deformation fabric (Sibson, 1977). Slower slip rates imply a more ordered fabric.

Foliated ultracataclasites are fabrics which have been dominated by frictional grinding. The zonal distribution of the fabrics and lack of discrete slip surfaces imply that intense shearing was pervasive throughout the fault-rock. Laboratory experiments have demonstrated that when sliding in sandstones is due to pervasive cataclasis, an incipient banding with layers of coarse and fine grained material is formed (Engelder et al., 1975). Shear deformation is distributed throughout, but banding results from variations in the intensity of cataclasis among different zones. This suggests that the fluxion-type banding observed in foliated ultracataclasites is due to flowage by pervasive cataclasis.

SLIDING MECHANISMS: A DISCUSSION

Velocity modes, or slip rates, acting during thrust emplacement are difficult to determine from deformation along exposed faults. For purposes of discussion, a bimodal distribution of velocity modes will be used, with two major groupings corresponding to aseismic and seismic failure. Within the elastico-frictional regime both modes of failure may occur (Sibson, 1977). Change from seismic to aseismic movement occurs at the brittle-ductile transition, with aseismic slip, in the form of cohesive cataclastic flow, occurring under ductile conditions (Orowan, 1960). The brittle-ductile transition is a function of confining pressure and fluid pressure. In laboratory experiments on sliding characteristics in a gouge-filled fault zone in sandstone blocks, the change from stable cataclastic flow to a slick-slip movement was caused by a decrease in effective normal stress (Engelder et al., 1975). This stress decrease could result from a decrease in confining pressure or an increase in fluid pressure.

The significance of abnormally high pore pressures in facilitating movement along overthrusts was initially pointed out by Hubbert and Rubey (1959). High fluid pressures reduce effective stress, and therefore critical shear stress necessary for slippage along the basal contact of a thrust sheet. However, in specific instances, cataclasis produces a permeable fabric that could not sustain steady-state, high pore pressures (cf. Brock and

Engelder, 1977). This effect would be enhanced when the thrust zone intersected the surface of the ground, providing a ready conduit for the release of high fluid pressures. While such observations are true for steady-state conditions, they do not preclude transient, high pore pressures.

Secondary porosities and permeabilities within the fault zone should remain high since deformation involves both fracture and rigid body rotation, indicating the absence of high pore pressures in the faulting process. However, the effects of rapid tectonic loading cannot be ignored (Gretener, 1979), because thrusting causes rapid loading, even under aseismic conditions. Also, high pore pressures need not be steady-state phenomena, but could be transient (cf. Gretener, 1979). Assuming first, saturated conditions along a fault zone, and second, a small amount of cataclastic deformation, then transient, high pore pressures could initiate large scale, rapid movement.

Two seemingly opposing facts pertaining to the nature of cataclasis may be found in the literature. As a bulk mechanism, cataclastic flow causes dilation (Paterson, 1976, p. 165; Sibson, 1977). However, laboratory experiments have shown that fault-gouge generation causes net decrease in porosity (Engelder et al., 1975).

This provides the components for rapid tectonic loading. Initial dilation at the onset of cataclasis increases porosity. Assuming high permeabilities, the newly created pore spaces would soon be saturated. If cataclasis continues, then gouge generation should result in a rapid decrease in porosity and permeability, thus leading to abnormally high pore pressures. This in turn, would lead to seismic failure which would enhance the loading effect and lead to further slippage. High permeabilities in the fault zone would allow rapid dissipation of high pore pressures. Engelder et al (1975) found that quartz gouge was sufficiently permeable to relieve excess pore pressures in 10 to 30 seconds. Assuming transient sliding rates of 10 to 100 cm s^{-1} (Brune, 1970), displacements of 1 to 30 meters could be facilitated by high pore pressures. Thus, it may be that steady-state high pore pressures are not necessary for seismic failure along thrust faults.

Deformed calcite veins and cavity-filling quartz stringers in many of the fault-rocks indicate that fluids migrated along the Saltville thrust during faulting. It is therefore possible that transient high pore pressures aided thrust movement. The thickness of the fault zone, and in particular the characteristics of the gouge, must also be explained by any proposed sliding mechanism(s).

Where observed, the Saltville thrust is defined by a thin fault zone. The effects of friction-dominated deformation decrease away from this zone and the associated sliding surfaces. Sibson (1977) noted that seismic failure occurs along planar slip surfaces. This is reasonable if the fault surface is lubricated to eliminate grinding. Perhaps relatively thin fault zones along the Saltville thrust trace indicate areas where most movement was accompanied by abnormally high pore pressures. Fault-rocks in the Saltville area contain zones of foliated ultracataclasites, indicating pervasive cataclasis as a sliding mechanism. The broad fault zone at Saltville (several meters thick) suggests that movement has not been along discrete surfaces, but within a zone.

Pressure-solution slip discussed by Elliott (1976) may also have been involved. This mechanism operates on discrete surfaces during aseismic failure. Fabrics resulting from pressure-solution slip resemble slicken-sides produced by abrasive scratching during frictional sliding, in that they exhibit fibers, grooves, and accretion steps (Elliott, 1976). Late stage stylolites produced during deformation along the Saltville thrust show rapid variations in thickness, micro-slickensides, large lenses of insoluble residue, and high silica content. The late formation of the stylolites suggests that they are related to locking of the fault surface, however, the micro-slickensides indicate some movement. The stylolites may be due to filling of cavities on an irregular surface during pressure-solution slip, or they may be due to late stage shearing which mobilized the residue and injected it into fracture cavities. Late stage shearing is favored for the Saltville thrust because flow structures are present in the stylolites and fibers are lacking.

CONCLUSIONS

Cataclasis has been the primary bulk deformation mechanism along the Saltville thrust. This has caused fracturing and rigid body rotation, suggesting that thrusting took place at depths of less than 10 km and below 250° C. The evolution of the fault-rock fabrics involved at least two periods of shearing and a late stage of stylolite development. The resultant fabrics range from protocataclasites to ultracataclasites and reflect increasing deformation intensity. Most fabrics have a matrix composition of 50 to 70 percent. Foliated cataclasites and ultracataclasites were produced through rigid body rotation, pressure-solution, and cataclastic flow.

Intermediate to high dips along the fault surface imply that exposed portions of the thrust were emplaced against gravity by a local horizontal compressive force. This does not imply that the regional deformation was also due to horizontal compression. Assuming that the exposed portions of the fault represent the concave-up portions of a listric-shaped thrust, then stress conditions are perhaps analogous to those at the toe of an overthrust (cf. Raleigh and Griggs, 1963).

Fault-rock fabrics can be related to deformation and sliding mechanisms along natural thrusts. On the basis of observed fabrics, emplacement of the Saltville thrust-sheet is considered to have occurred in a caterpillar-like fashion (Gretener, 1972), with movement by both seismic and aseismic failure. Seismic failure was facilitated by transient, high pore pressures, whereas aseismic failure was probably accomplished within a layer of cataclastically flowing gouge.

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APPENDIX I

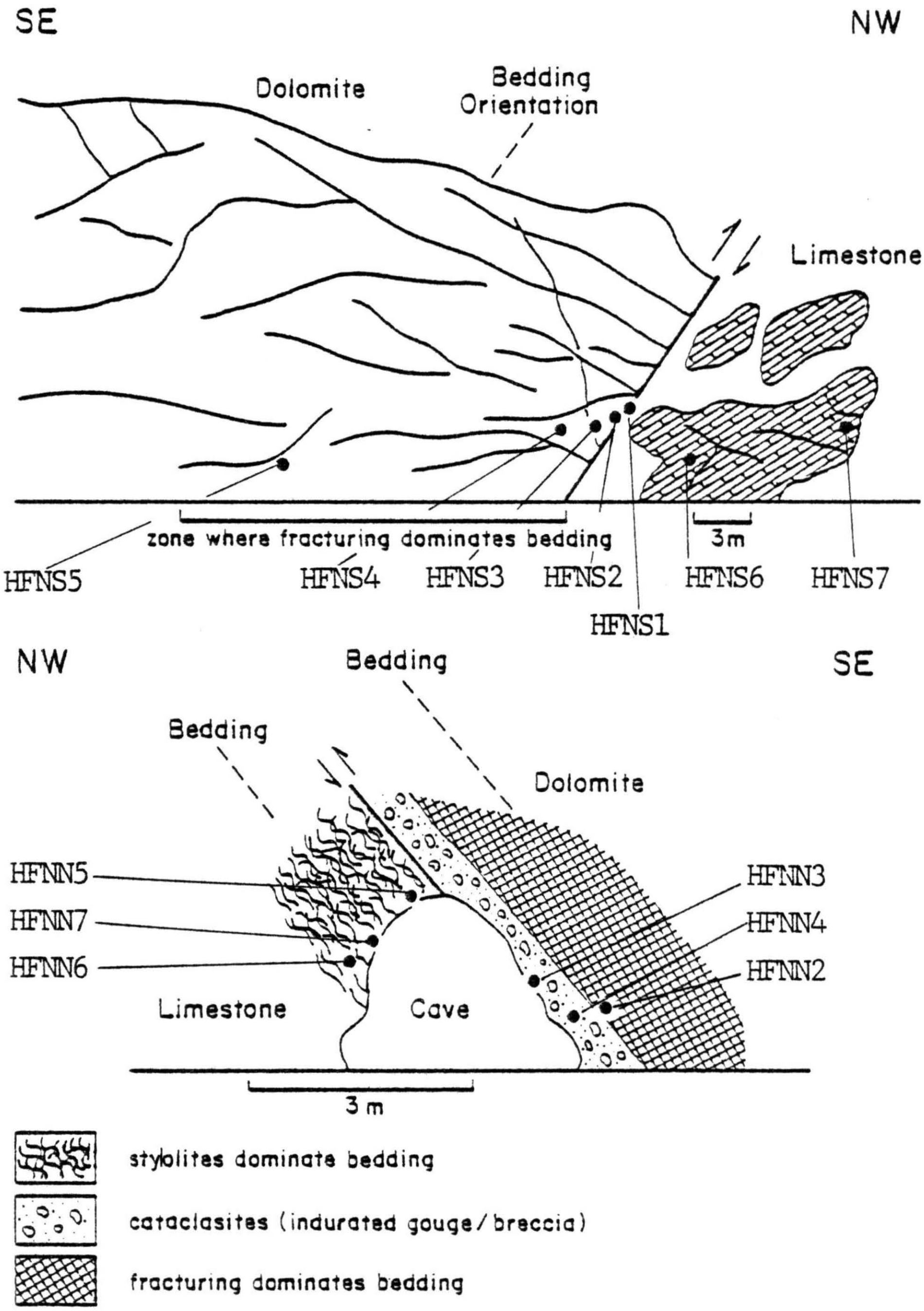
Lithologic descriptions of stratigraphic units at the northern terminus of the Saltville thrust (modified after Gambill, 1974).

System	Series	Formations	Description
Devonian Silurian			Undifferentiated Millboro Shale, Huntersville Chert, Rocky Gap Sandstone of Early Devonian age and Tonoloway Limestone of Late Silurian age.
	Wenlockian	Keefer Ss.	White to reddish-white, fine- to medium-grained, medium- to thick-bedded orthoquartzite; cross-bedding and local *Scolithus* structures common.
	Llandoverian	Rose Hill Fm.	Maroon, iron-rich, thin- to medium-bedded sandstones and shales; quartz grains cemented with crystalline hematite.
		Tuscarora Ss.	White to light-gray orthoquartzite and quartzitic sandstone, in part, conglomeratic; cross-bedding, ripple marks, and local *Scolithus* structures common.
Ordovician	Cincinnatian	Juniata Fm.	Dark red and olive-green shales and thin-bedded, brownish-red siltstones and sandstones; light brown to white medium-bedded sandstone at top
		Martinsburg Fm.	Interbedded dark-gray, thin-bedded, coarse-grained, skeletal limestone and brown shale at base; grades to yellow-brown shale; minor siltstones and sandstones at top.
	Champlainian	Eggleston Fm.	Brown and gray, thin-bedded limestones, siltstones, and shales; several interbedded bentonites, some with subjacent silicified cuneiform jointed beds.

Ordovician (cont.)		Moccasin Fm.	Red and green calcareous, silty mudstone and interbedded sandstone and conglomeratic sandstone; in part fracture-cleaved.
		Witten Ls.	Gray, locally cross-bedded intraclast, ooid, and skeletal grainstones, and algal mat boundstones.
		Benbolt Ls.	Black, argillaceous skeletal packstones and wackestones and gray, skeletal grainstones at top.
	Champlainian	Pearisburg-Lincolnshire Ls.	Black, cherty, skeletal packstones and wackestones, gray skeletal grainstones and algal mat boundstones.
		Five Oaks-Elway Ls.	Black, very cherty skeletal limestones; gray argillaceous lime mudstones; and gray lime mudstones with birdseye textures.
		Blackford Fm.	Gray and red, medium- to thick-bedded, argillaceous dolomite and dolomitic limestones; basal chert and dolomite conglomerate.
		Major Unconformity	
	Canadian	Upper Knox Dol.	Gray, medium- to thick-bedded cherty dolomite with interbedded limestones.
	Croixian	Copper Ridge Fm. (Lower Knox)	Gray, thin- to medium-bedded cherty dolomite with interbedded rusty-brown, carbonate-cemented sandstones and oolitic chert.
		Nolichucky Shale	Light-brown shale and/or gray dolomitic shale.
	Albertian	Honaker Dolomite	Dark- to light gray dolomite

APPENDIX II

Sample locations and numbers for fault-rocks used in the investigation of cataclastic fabrics and sliding mechanisms.



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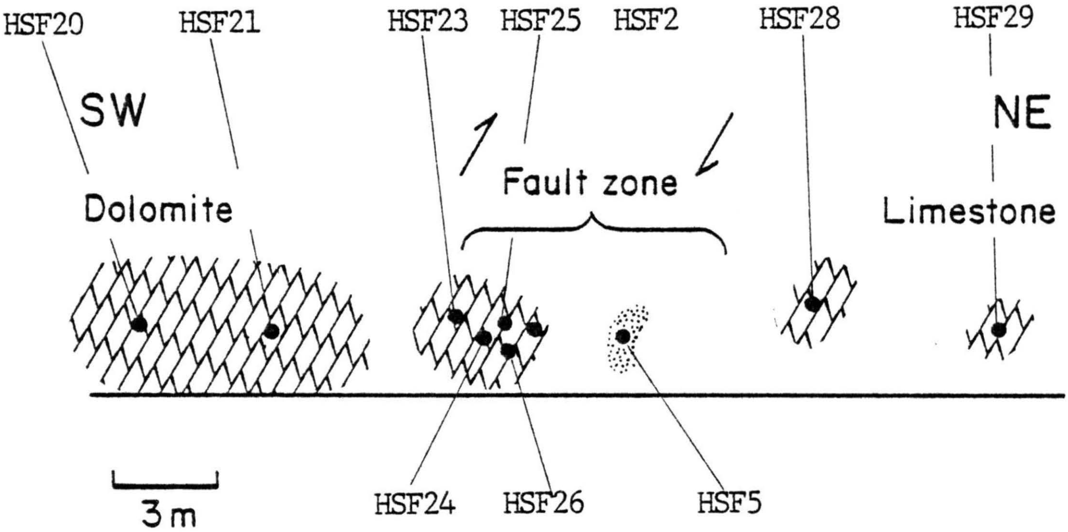
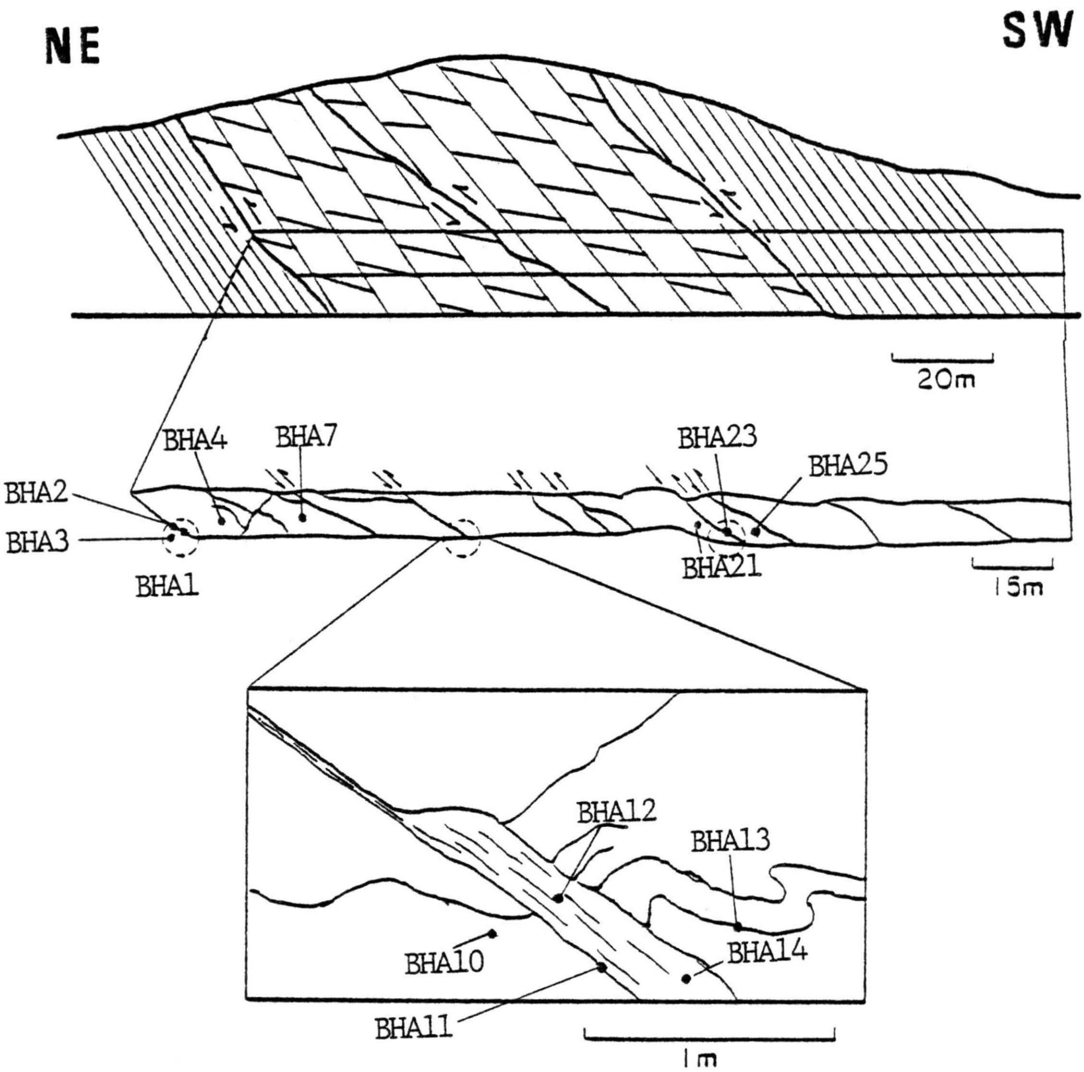


Saltville, Virginia



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THE SALTVILLE THRUST: INVESTIGATION OF A REGIONAL THRUST FAULT IN A FORELAND FOLD AND THRUST BELT

by

William Meredith House

(ABSTRACT)

Thin-skinned models of deformation are currently accepted for the southern Appalachians. The mechanics of this type of deformation are not well understood. The Saltville thrust, a major overthrust in the southern Appalachians, was investigated with respect to deformation mechanics. Thrust termination occurs in the overturned, northwest facing Sinking Creek anticline, at the juncture between the southern and central Appalachians. The primary regional displacement transfer mechanism at the thrust terminus is the transition from faulting to folding. Mesoscopic fabrics show variations in deformation intensity across the anticline, with high strains on the northwest limb, and low strains on the upright southeast limb. Strain accommodation on the overturned limb was by folding, faulting, and cleavage development. Knox Dolomite in the core of the anticline is upward facing and unfolded. Strain patterns and facing data indicate that shear thrusting at depth caused passive regional folding. Subsequent movement caused the

thrust to act as a break thrust and cut previously folded strata.

Cataclasis is the primary bulk deformation mechanism along the thrust surface. Cataclastic fabrics in dolomites range from protocataclasites to ultracataclasites, and reflect changes in frictional grinding. Foliated cataclasites are described. Fault-rock fabrics indicate that thrust-sheet emplacement occurred through seismic failure, facilitated by transient, abnormally high pore pressures, and aseismic failure accomplished within a layer of cataclastically flowing gouge. Thin fault zones and rapid decreases in deformation intensity away from the fault surface indicate rapid sliding, and a lack of frictional grinding.