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PAMPHLET

Cross-Strike Structural Discontinuities and Lineaments of the Central Appalachians

By

C. Scott Southworth, U.S. Geological Survey

Abstract

Seven cross-strike structural discontinuities (CSD's), 100 lineaments, and 8 allochthonous-block and crustal-block boundaries, recognized by various workers in the Central and Southern Appalachians, are compiled on a side looking airborne radar (SLAR) image mosaic of twelve $1^{o}x2^{o}$ quadrangles to better understand their relationship to the regional structural framework. CSD's are broad zones of structural disruption that may contain many lineaments of varying size and orientation. Geologic and geophysical data suggest that some Appalachian CSD's and lineaments are the surficial expression of allochthonous-block and crustal-block boundaries. The high-resolution, synoptic view and detailed expression of surficial morphology on X-band SLAR images provide a preliminary means of mapping CSD's and lineaments on the basis of alignment or disruption of structural and geomorphic patterns.

Of the seven CSD's, two appear to involve basement, three appear to involve lateral ramps in cover rocks above basement (zones where a thrust fault transfers to a higher stratigraphic level along regional strike), and two may involve both basement and cover rocks. Of the 100 lineaments, 14 appear to involve basement, 78 are restricted to the allochthon cover rocks, and 8 may involve both basement and cover rocks. Thirty-two percent of all lineaments are attributed to the surficial expression of lateral ramps while 48 percent are attributed to interruptions in strike, such as regional-scale plunging fold noses and geomorphic gaps.

CSD's and lineaments are an exploration target for natural gas because they are areas where fracture permeability is enhanced. The spatial relationship of CSD's and lineaments to gas fields in the Valley and Ridge province suggests structural closure of anticlinal traps due to differential movement associated with lateral ramps.

Acknowledgements

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Introduction

The objectives of this investigation are to compile data of cross-strike features identified by various workers as CSD's, lineaments, and allochthonous and crustal-block boundaries of a portion of the Appalachian fold belt, to better understand their relationship to the regional structural and physiographic framework. Although research on the subject has been conducted for over 20 years, no comprehensive review exists. Only those CSD's, lineaments, and block boundaries, which previous workers defined by using field geologic and(or) geophysical data are included; numerous lineaments derived from image interpretations of the Appalachian region (Trask and others, 1977, Reynolds, 1979, Carter, 1983, Wise and others, 1985, and Lang and others, 1985), which lack supporting geologic and geophysical data, are not included; recognition of the same lineaments by several authors suggests potential structural zones. However, supporting geologic and geophysical data are necessary prior to their acceptance.

Terminology is confusing and warrants explanation. Features described in this investigation are classified as either lineaments (O'Leary and others, 1976) or CSD's (Wheeler, 1980). The distinction between lineaments and CSD's is the degree of geologic investigation of the features. Lineaments "presumably reflect a subsurface phenomenon" (O'Leary and others, 1976) whereas detailed geologic investigation of CSD's defines surface and subsurface geologic phenomenon. Broad lineaments which are expressed in geomorphic, structural, sedimentologic and geophysical data may be classified as CSD's if the criteria by Wheeler (1980) are met. CSD's have been termed structural lineaments. However, CSD's are generally better defined and mapped than are lineaments (Wheeler, 1980). The classification of features by previous workers was generally accepted by the present author; exceptions were features initially termed lineaments, such as the Petersburg (Sites, 1978), Tyrone-Mount Union (Kowalik, 1975), and Modoc (Dean and others, 1979) (see map sheet) and later called CSD's (Wheeler, 1980). In cases such as these, the present author classified the features based on the published data and the definitions of O'Leary and others (1976) and Wheeler (1980).

The CSD's, lineaments, and block boundaries are compiled and overlaid on a high-resolution, synoptic SLAR image mosaic to enable the reader to make correlations and interpretations of these possible structures with respect to physiographic features (map sheet). This compilation does not reflect the present author's interpretation of the SLAR image mosaic.

Compilation

CSD's, lineaments, and allochthonous-block and crustal-block boundaries reported in the geologic literature were compiled on a USGS 1:250,000-scale Universal Tranverse Mercator (UTM) base map reduced to scale 1:500,000. Sources of error in the compilation include cartographic inaccuracy by authors, differing map projections, and geometric distortions inherent in printing and reproduction. No attempt was made to correct these errors while compiling the map. It was decided that the amount of information shown on the compilation may impede the interpretation of the data. Therefore separate thematic maps (lineaments, lateral ramps, CSD's, allochthonous/crustal blocks, and the relationship of CSD's and lineaments to oil and gas fields) were produced (figs. 2-6).

SLAR Mosaic

SLAR is an active sensor which uses electrical energy, 3.1 cm wavelength (X-band) in this case, to illuminate and image the terrain. SLAR return in heavily vegetated terrain, such as the Appalachians, is primarily influenced by the roughness of the vegetation canopy and by the dielectric properties of the vegetation. Theoretically, as the wavelength of the SLAR signal increases, penetration through the vegetation to the soil and bedrock is possible (Raines and Canney, 1980). High depression angles may also account for some penetration of SLAR energy through light vegetative cover (Correa, 1980). However, the relatively short wavelength and low depression angle of this SLAR (table 1) primarily provides backscatter of the dense deciduous-tree canopy which generally conforms directly to topography. The physiographic expression provided by SLAR is unmatched, although multispectral data provided by Landsat, as well as color-infrared aerial photographs, enable the detection of lineaments with geobotanical expression.

The base map for the compilation overlay is a 1:500,000-scale SLAR image mosaic consisting of twelve $1^{o}x2^{o}$ (1:250,000-scale) quadrangle map-controlled SLAR image mosaics (map sheet). Each $1^{o}x2^{o}$ quadrangle image map consists of approximately 10 to 12 SLAR image swaths manually mosaicked and geometrically controlled to identified points scaled from the corresponding $1^{o}x2^{o}$ quadrangle map. Contact prints at 1:500,000-scale, produced from film negatives (50% photographic reduction), were manually mosaicked. Specifications for the SLAR image data are listed in table 1.

Regional Geology and Physiography

The area of study includes the Valley and Ridge and Plateau provinces of a portion of the Central and Southern Appalachians (fig. 1). This area is composed of Paleozoic sedimentary rocks ranging in age from Cambrian to Permian (fig. 1). With exception of the "Ohio Line" (Hobbs, 1904), lineaments and CSD's are restricted to the Valley and Ridge and Plateau provinces. The Valley and Ridge province is bounded on the east by the Blue Ridge province which consists of Precambrian to Paleozoic age igneous and metamorphic rocks (fig. 1). The sharp contrast in the textural fabric of the igneous and metamorphic rocks of the Blue Ridge province and the carbonate rocks of the Great Valley to the west is readily seen on the SLAR image (map sheet).

Surficial expression of anticlines and synclines, due to thrust faulting and folding of the allochthonous cover rocks (Rich, 1934) i.e., thin-skinned tectonics (Rodgers, 1949), consists of resistant sandstone, quartzite, and cherty carbonate rocks on fold limbs which form long sinuous ridges with intervening shale and carbonate-rock valleys. The anticlines result from the imbricate stacking of strata by ramping thrust faults, and the synclines are a passive product of anticlinal growth (Gwinn, 1964). Broad fold amplitudes in Pennsylvania change to narrow fold amplitudes in the Southern Appalachians (map sheet). This is chiefly due to deformation in the Southern Appalachians which is dominated by thrust faults alternating with synclines (Harris and Milici, 1977). The regional northeast strike of the Central Appalachians changes to east-northeast at the Pennsylvania salient in the northern part of the study area; the Central Appalachian northeast strike changes to west-southwest at the juncture zone of the Central and Southern Appalachians, in the southern part of the study area (map sheet). The sharp change in physiography from long linear ridges with trellis and rectangular drainage to intensely dissected dendritic drainage patterns (map sheet) reflects the contrast in styles of deformation from folded and faulted rocks of the Valley and Ridge to less deformed gently dipping to flat-lying rocks of the Appalachian Plateau (fig. 1). This change occurs at the Allegheny structural front.

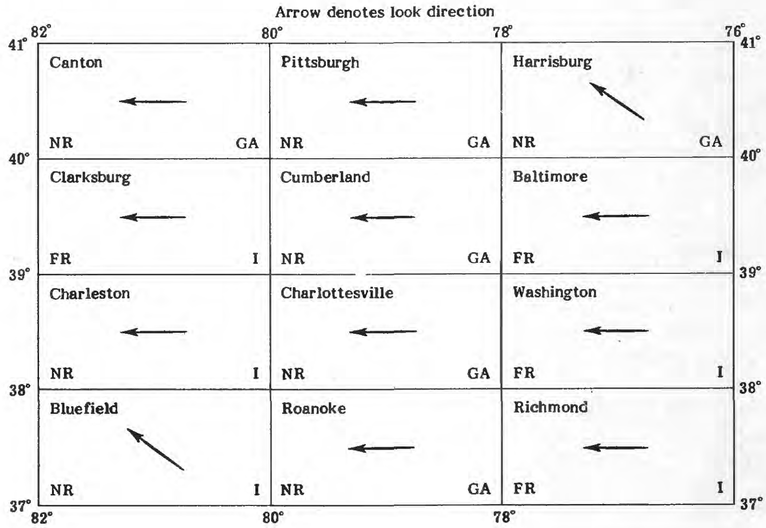
Compiled Elements

1) Lineaments

Lineaments have been defined as "mapable, simple or composite linear feature(s) of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ distinctly from the patterns of adjacent features and presumably reflect a subsurface phenomenon" (O'Leary and others, 1976). Central Appalachian cross-strike lineaments were interpreted from geologic data by Hobbs (1904), Rodgers (1963, 1970), Drake and Woodward (1963), Gwinn (1964), Woodward (1968), and Kowalik and Gold (1976). Hobbs (1904) identified the "Ohio Line" (map sheet) extending from the Chesapeake Bay through the Appalachians, paralleling the James River, to the Ohio River, from the analysis of hydrographic and topographic map separates. Based on patterns of fold trends and subsurface structures, Rodgers (1963, 1970) suggested that lineaments in the Appalachian Plateau province were strike-slip faults that bound the edges of thrust sheets. Woodward defined the Cornwall displacement, also known as the Cornwall-Kelvin wrench fault (map sheet), using regional geologic trends and Paleozoic isopach maps which suggest 80-90 miles of right-lateral movement across the Piedmont, Blue Ridge, Valley and Ridge, and Plateau provinces (Drake and Woodward, 1963). Using surface and subsurface structural data of anticlines, Gwinn (1964) proposed an origin for lineaments as zones where

Table 1. Index to SLAR $1^{\circ} \times 2^{\circ}$ quadrangle image mosaics shown on map sheet

	Contractor	
	Intera (I)	Goodyear Aero Service (GA)
Data acquisition date	May 1984	Sept 1982 (Oct/Nov 1984-Canton)
Depression angle	22° (near range)(NR) 11° (far range) (FR)	10°-33° (far range to near range) 14°-27° (far range to near range)
Altitude	10 km	12 km
Swath width	46 km	37 km



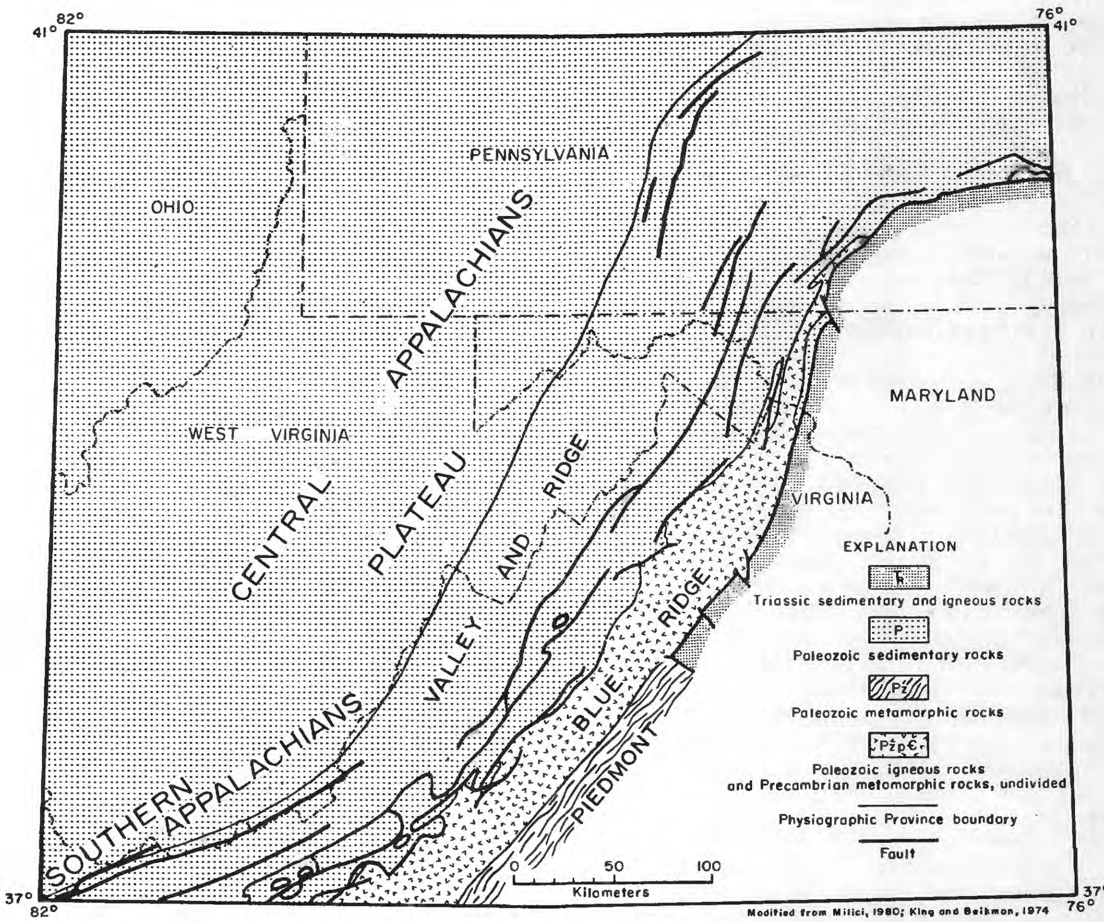


Figure 1. Generalized geologic and physiographic map of a portion of the Central Appalachians.

buried thrust detachments changed stratigraphic position along strike or where tear-faulting occurred. Woodward (1968) interpreted interruptions in strike as lineaments based on physiography, surficial structure, and limited subsurface structure. Kowalik and Gold (1976) described long lineaments interpreted from Landsat images as probably the surface expression of buried tear faults or ramps ("Gwinn-type" lineaments) in the Paleozoic strata overlying basal Appalachian decollements. In addition, Kowalik and Gold (1976) suggested that many of the shorter lineaments trending oblique to strike may be related to tear faults and ramps associated with listric thrust faults.

Numerous lineaments of the Central Appalachians have been interpreted from regional gravity and magnetic data (map sheet). King and Zietz (1978) defined the 1600-km-long New York-Alabama lineament (map sheet) based on a series of prominent linear magnetic gradients. They suggested that the lineament reflects a discontinuity in basement with substantial strike-slip displacements and may represent a rigid block boundary or basement suture. Kulander and Dean (1978) suggested a lateral ramp from Cambrian to Ordovician strata, across the Petersburg lineament (map sheet) based on alignments of terrain-corrected Bouguer gravity gradient and disruptions in magnetic data. Lavin and others (1982) defined the Lake Erie-Maryland block, bounded by the Pittsburgh-Washington and Tyrone-Mount Union lineaments (map sheet), using Bouguer gravity and aeromagnetic data. Lavin and others (1982) inferred that the block moved 60 km northwestward during late Precambrian to early Ordovician time. Kane (1983) used Bouguer gravity data of wavelength less than 250 km (Hildenbrand and others, 1982) to interpret the crustal structure of the Appalachian basin as a rift complex offset by transform faults, analogous to the Mid-Continent region. Rice (1983) interpreted changes in trends and patterns of magnetic (Zietz and others, 1980) and gravity (Hildenbrand and others, 1982) anomalies as lineaments reflecting crustal rift structure. Rice (1983) interpreted cross-strike gravity and magnetic profiles to suggest left-lateral offsets of the Rome trough at the geophysical lineaments.

In summary, of 100 Appalachian lineaments, 14 are thought to involve basement, 78 only cover rocks above basement, and 8 both cover rocks and basement (fig. 2). Of the 78 lineaments restricted to the cover rocks, 27 are believed to represent the surface expression of lateral ramps and 48 are attributed to interruptions in strike from regional-scale plunging fold noses. Of the eight lineaments which are believed to involve both cover rocks and basement, five are thought to be the surface expression of lateral ramps.

Butler (1982) termed ramps which strike parallel to the transport direction with dominantly strike-slip displacement as lateral ramps. The orientation of lateral ramps can be either parallel or oblique to the direction of tectonic transport and may represent zones where a thrust fault cuts upsection to a shallower structural and stratigraphic level along strike. Similar concepts of lateral ramps have been advanced by previous workers. Rich (1934) described the cross-strike structures of the Cumberland Plateau as disturbance zones having the appearance of incipient tear faults separating blocks of differential westward movement. Wilson and Stearns (1958) recognized vertical cross faults on the Cumberland Plateau as buried thrust faults which turn and become buried strike-slip faults. Rodgers (1963) identified conjugate sets of strike-slip faults on the Plateau whose origin he attributed to thrust faults cutting upward to the surface where they form blunt noses of anticlines or margins of detached blocks. Gwinn (1964) cited Plateau cross-strike lineaments as zones below which sole thrusts or step thrusts change stratigraphic position along strike resulting in a buried tear fault. Kowalik and Gold (1976) stated that lineaments defined by alignments of abruptly plunging ends of long, continuous folds are due to "stepped" tear and ramp faults, or laterally restricted thrusts, which change stratigraphic position along strike. Sites (1978) suggested a northeast-dipping lateral step (ramp) from detachment in Cambrian shales to detachment in Ordovician shales across the Petersburg lineament in the Valley and Ridge of West Virginia. Kulander and Dean (1978) used gravity data to define a northeast dipping transverse decollement step (lateral ramp) from Cambrian to Ordovician decollements forming the section of the Petersburg lineament zone beneath the folded Plateau. Wheeler (1978) described ramp (parallel to strike) and step (perpendicular to strike) combinations as probable structural mechanisms of CSD's. Dean, Kulander, and Williams (1979) interpreted Appalachian cross-strike lineaments or block boundaries to be manifestations of northward-dipping transverse steps (lateral ramps) connecting different decollement horizons. Wilson (1980) described a northeast-dipping transverse decollement step (lateral ramp) from Ordovician to Silurian and Devonian decollements across the Parsons lineament. Using lineament isopleth data, Lang (1982) interpreted a northeast-dipping lateral ramp associated with the Lost River, W.Va. gas field. Simmons (1983) described a southwest dipping lateral ramp at the Valley and Ridge extension of the Parson's lineament. Rodgers and Anderson (1984) attributed changes in structural elevation across the Tyrone-Mount Union lineament to either basement uplift or change in stratigraphic level of the basal decollement (lateral ramp). Pohn and Southworth (1984) suggested the occurrence of several lateral ramps in the Central Appalachians based on SLAR image analysis of fold wavelength and field mapping. And lastly, Pohn and others (1985) describe Central Appalachian lateral ramps and their relationship to gas fields.

Lateral ramps, suggested by geologic and geophysical data of CSD's and lineaments, are shown in figure 3. Of the eight lateral ramps believed to be associated with CSD's and lineaments of the Central Appalachians, four are thought to involve transfer from early to middle Cambrian (Rome Formation) to Late Ordovician (Martinsburg shale) decollements, and two are thought to involve Late Ordovician (Martinsburg) to Late Silurian (Tonoloway Limestone?) and Late Devonian (Brallier Shale?) decollements. Two lateral ramps dip southwest as opposed to northeast; one is confined to the Upper Devonian Brallier and one to Ordovician carbonate rocks (H. Pohn, 1985, oral commun.). The concentration and paucity of lateral ramps in figure 3 is partly a function of bias by geographic investigation.

2) Cross-Strike Structural Discontinuities (CSD's)

CSD's are broad, diffuse, transverse zones of structural disruption in allochthonous fold and thrust belts; they are recognizable because they disrupt strike-parallel structural, geophysical, geomorphic,

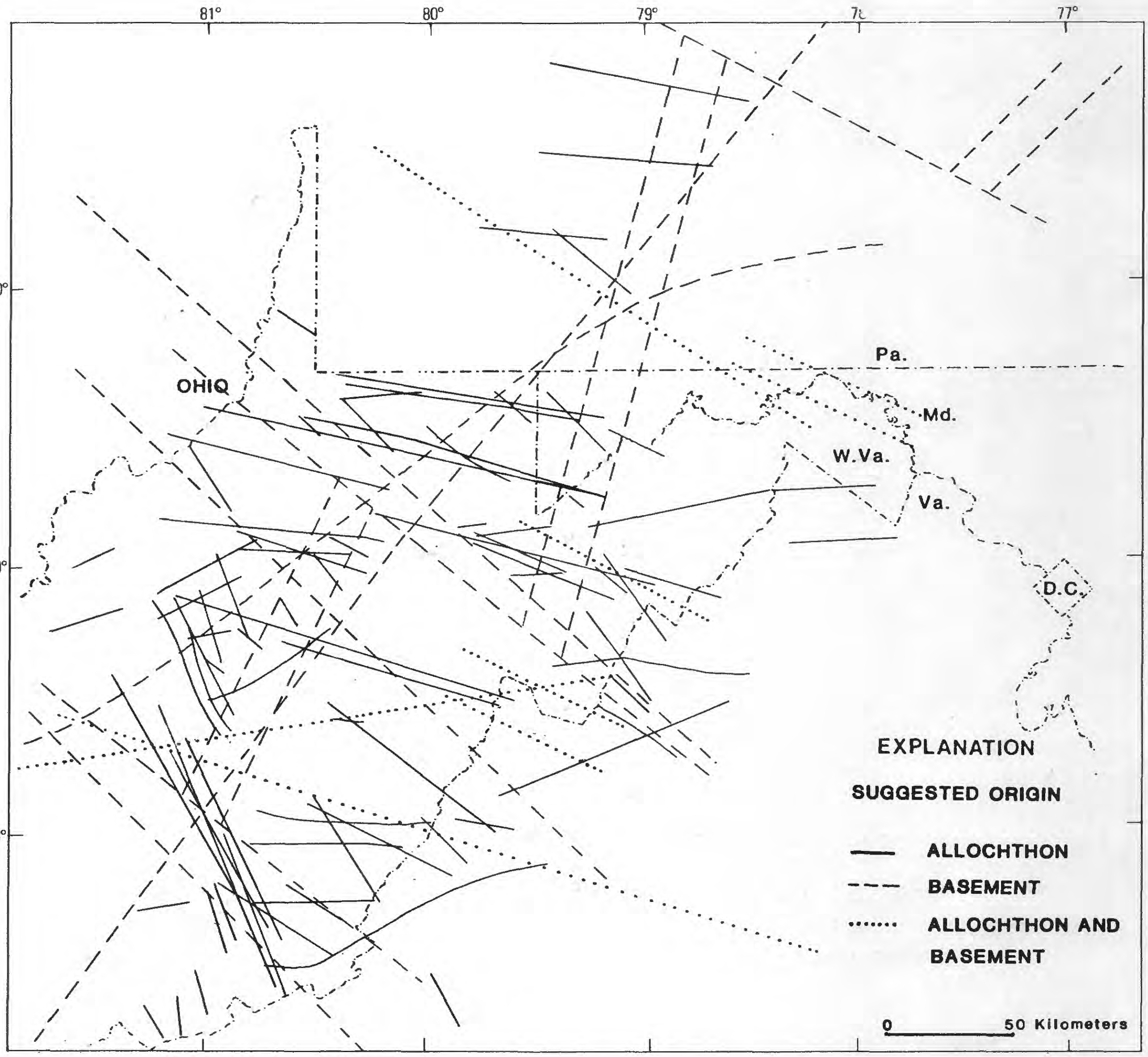


Figure 2. Lineaments of the Central Appalachians keyed to their suggested origin.

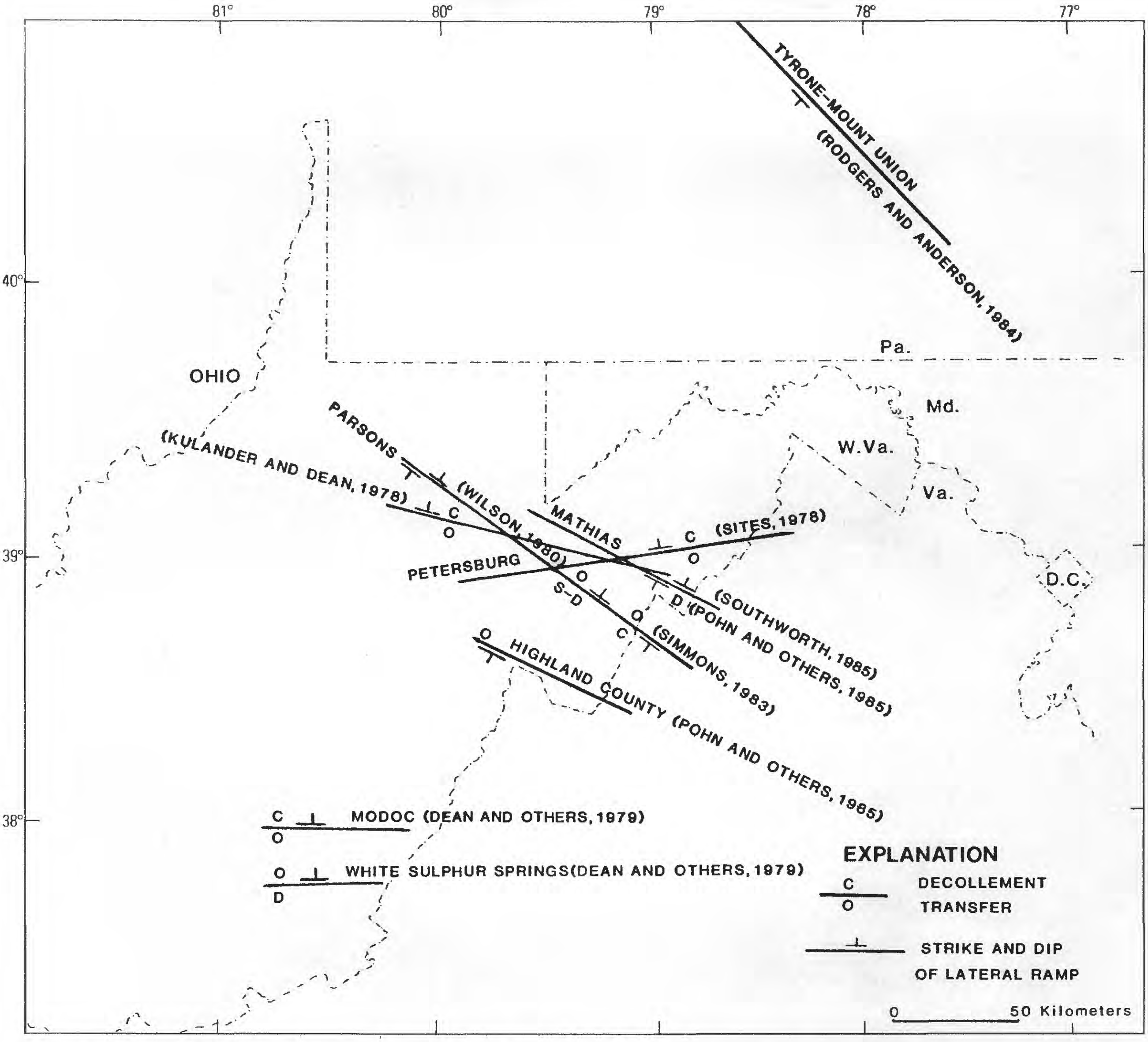


Figure 3. Lateral ramps of the Central Appalachians. Letters C (Cambrian), O (Ordovician), S (Silurian), and D (Devonian) represent change in decollement level suggested for the lateral ramp(s).

sedimentologic, and other patterns (Wheeler, 1980). CSD's are broad zones which may contain many lineaments of varying size and orientation (Trumbo, 1976) and are believed to represent boundaries of large blocks which have undergone differential transport.

Wheeler (1980) characterized the median dimensions of CSD's from three orogenies to be typically at least 3.5 km wide, 4 km deep, 70 km long, with a 25-km centerline spacing. From this description, he concluded that the typical CSD involved about 980 km^3 of rock, an amount volumetrically comparable to many Central Appalachian folds. The average dimension of the 7 Central Appalachian CSD's cited in this report is 10 km wide and 115 km long.

Suggested models (Sites, 1978, Wheeler and others, 1979) for the mechanism of CSD's include: 1) active and(or) passive basement involvement (extension from basement structure or inactive basement structure influences overriding thrust sheets) such as the Tyrone-Mount Union (Kowalik, 1975, Rodgers and Anderson, 1984) (see map sheet), 2) transverse wrench fault and(or) decollement transfer zones in the cover rocks (ramps perpendicular to transport (frontal ramp) such as the Petersburg lineament (Sites, 1978) (map sheet) and ramp parallel to transport (lateral ramp) such as the Petersburg lineament zone (Kulander and Dean, 1978)) (map sheet) and 3) combination of any of the above, such as the Parson's lineament (Wilson, 1980) (map sheet).

Factors controlling the origin and propagation of CSD's are not understood (Sites, 1978, Wheeler, 1983). CSD's cross physiographic and structural provinces, and some geologic and geophysical data suggest basement involvement throughout geologic time (Southworth, 1986). Recurrent movement along northwest striking basement faults has been suggested for CSD's in the Appalachians (Drahovzal, 1976, Lavin and others, 1982, Rodgers and Anderson, 1984), Canadian Rockies (Price and Lis, 1975), and the British Caledonides (Horne, 1979). CSD's and lineaments as zones of reactivation are evidenced by changes and pinchouts in stratigraphic facies in Devonian (Sites, 1978, Wheeler, 1983) and Mississippian through Permian (Sites, 1978) sedimentary rocks along the Petersburg lineament (map sheet), Devonian sedimentary rocks along both the Fairmont-Rowlesburg and the Bartow lineaments (map sheet) (Wheeler, 1983), and Devonian through Pennsylvanian sedimentary rocks along the Tyrone-Mount Union lineament (Rodgers and Anderson, 1984). However, the inference that the upward propagation of basement structures causes a weak zone in which the cover rock decouples and deforms independently during thrusting is not adequately demonstrated.

In summary, of the seven Central Appalachian CSD's, two are believed to involve basement, three are thought to involve only lateral ramps in cover rocks, and two are thought to involve both (map sheet and fig. 4). Wheeler and others (1979) indicate that of six Southern Appalachian CSD's, two involve basement, three involve only lateral ramps, and one involves both. Thus about 70 percent of Appalachian CSD's are inferred to have involved intra-allochthon processes, with or without basement involvement, and are attributed to the surficial expression of lateral ramps.

3) Allochthonous and Crustal Blocks

The concept of major allochthonous blocks and crustal blocks in the Central Appalachians has been advanced by Rodgers (1963 and 1970), Gwinn (1964), Kowalik and Gold (1976), Kulander and Dean (1978), and Lavin and others (1982). Lineaments form the block boundaries and are attributed to the surficial expression of tear faults, or conjugate sets of strike-slip faults, which form the boundary of partially decoupled thrust blocks which have been transported semi-independently. The namesake anticline which forms the western margin presumably formed by movement of the detached block (map sheet and fig. 5).

Lavin and others (1982) defined the Lake Erie-Maryland (LEM) crustal block (map sheet and fig. 5) by analyses of regional gravity and magnetic data, Landsat images, and geological data. The LEM crustal block is bounded on the north by the Tyrone-Mount Union lineament (map sheet) (Kowalik and Gold, 1976) and is bounded on the south by the Pittsburgh-Washington lineament (map sheet). Geological and geophysical data support 60 km of lateral displacement of the block during late Precambrian to Early Ordovician time with subsequent vertical movement (Lavin and others, 1982).

The Use of CSD's and Lineaments for Gas Exploration

CSD's are an exploration target for natural gas because they are an area where fracture permeability is enhanced (Wheeler, 1980). Drilling within CSD's at intersecting short photolineaments in thrust sheets, has been an exploration strategy for structurally trapped gas in Devonian strata in the eastern part of the Plateau province (Wheeler, 1980). The Dry Fork, W.Va., gas field was discovered in the Oriskany Sandstone just west of the Allegheny front at the intersection of the Petersburg and Parson's CSD's (Patchen and others, 1985). Lineaments define an exploration target for natural gas because they represent the surficial expression of fracture zones which are believed to extend to fractured reservoir rock; high gas yields for wells located on or near lineaments support this (Wheeler, 1980, Goetz and Rowan, 1981).

The spatial relationship of CSD's and lineaments to the Bergton and Lost River gas fields in the Valley and Ridge province of Va. and W.Va., suggests termination of gas fields, by structural closure of anticlinal traps, due to differential movement along the cross-strike feature (fig. 6). Differential movement may have occurred if the CSD's and lineaments represent domain boundaries of differential tectonic transport. The domain boundary concept of lineaments in the Central Appalachians has been advanced by Rodgers (1963), Gwinn (1964), Kowalik and Gold (1976), and Kulander and Dean (1978). The domain-boundary concept is analagous to compartmental deformation of segmented fold trends in basement-involved foreland areas of the Rocky Mountains (Brown, 1984). Walker (1985) stated that cross faults which offset the Ricinus field, Alberta, probably represent different distances of thrusting from the west. The North and South Ricinus faults (Walker, 1985), when projected across strike, coincide with the terminations of the Ferrier and Willesden Green fields and the Caroline field, respectively. Recent discoveries in the Whitney Canyon-Carter Creek field, Painter field, and Anschutz Ranch field in

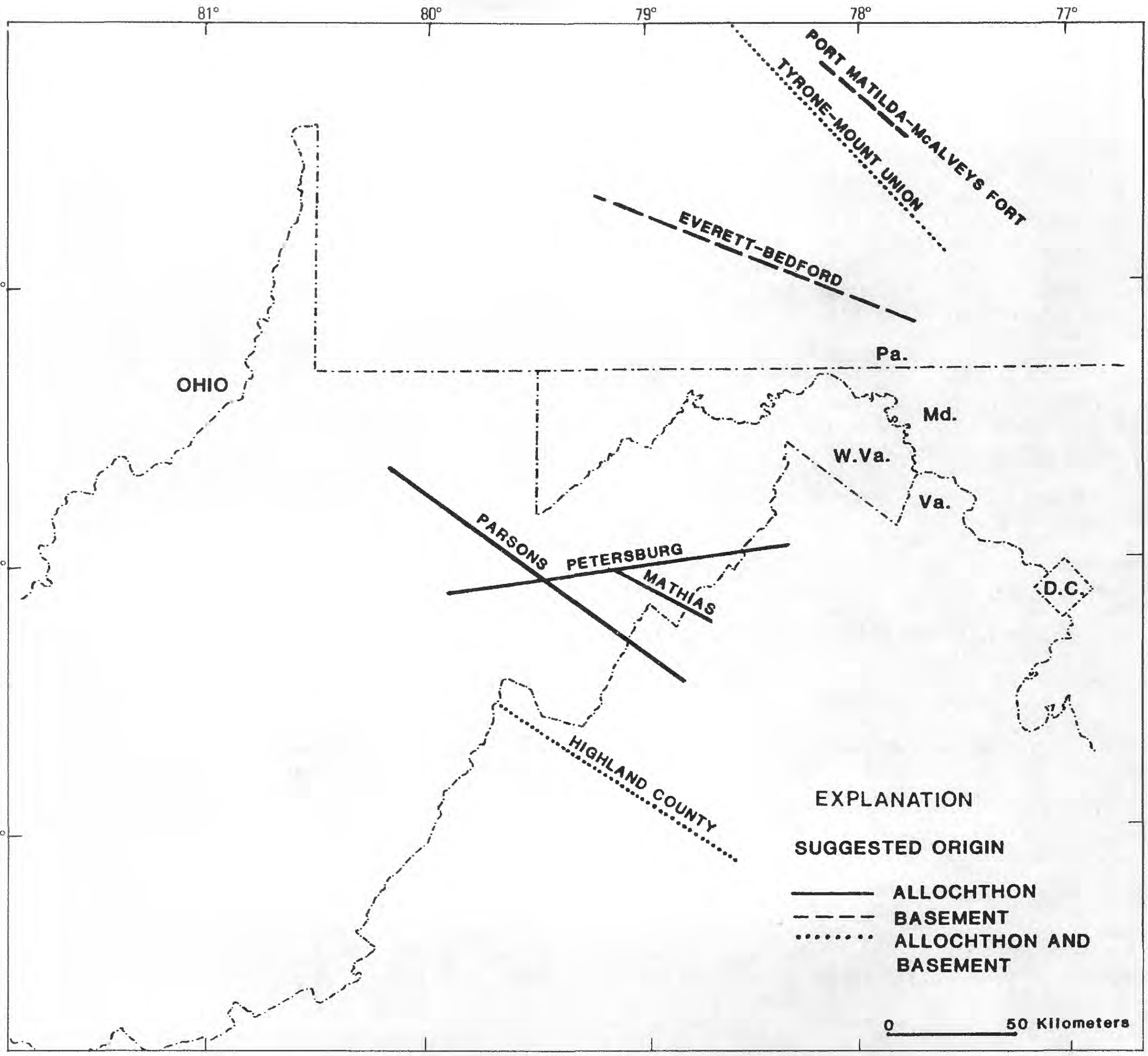


Figure 4. Cross-strike structural discontinuities (CSD's) of the Central Appalachians keyed to their suggested origin.

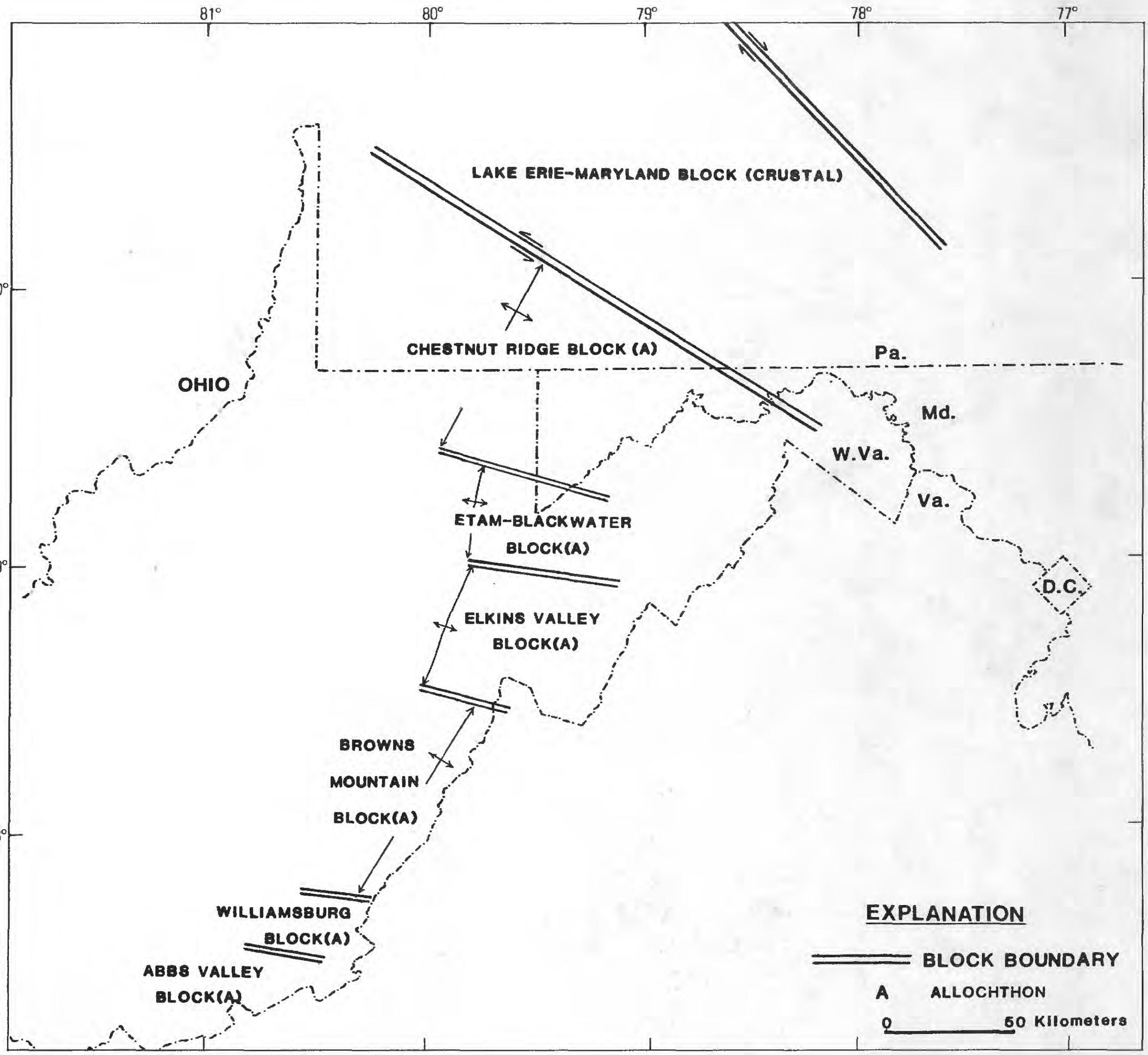


Figure 5. Allochthonous and crustal blocks of the Central Appalachians.

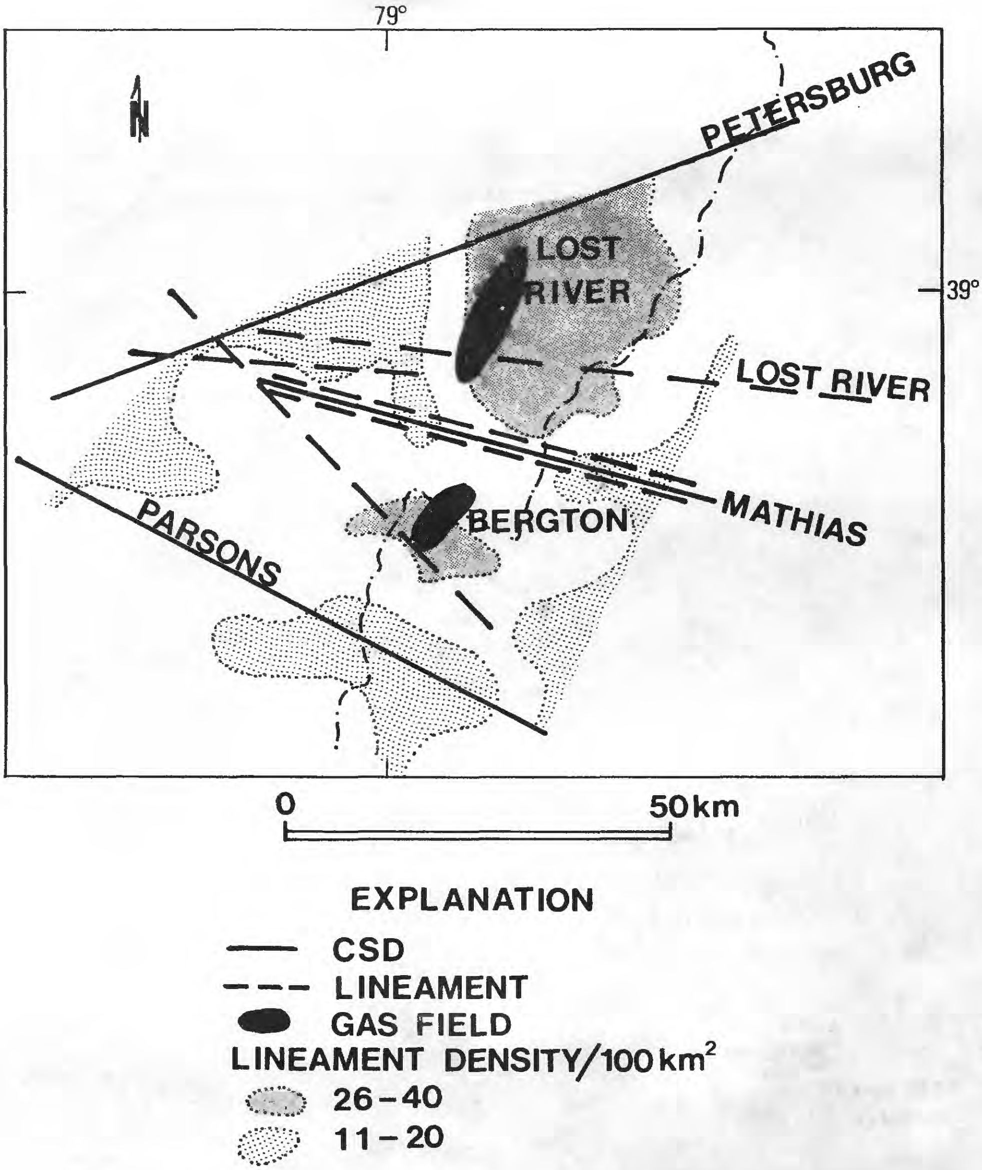


Figure 6. The relationship of CSD's and lineaments of the Valley and Ridge of the Central Appalachians to the Bergton and Lost River gas fields, Va., WVa. Lineament density isopleth data from Lang and others (1985).

the Utah-Wyoming overthrust belt demonstrated that lateral ramps can produce strike closure of paired longitudinal oil and gas fields separated by high-angle transverse faults (Boyer, 1985).

Structural interpretation of seismic data of the Lost River, W.Va. gas field by Columbia Gas Transmission Corporation defines the Lower Devonian Oriskany Sandstone reservoir as an anticline with three faulted domal highs along strike (Lang and others, 1985). Each domal high is laterally bounded by an increase in number of subsurface antithetic and synthetic thrust faults. Boyer (1985) suggested that strike closure and four-way closure of hydrocarbon traps in fold and thrust belts would not exist but for the presence of lateral ramps. The southern structural termination of the Lost River field corresponds with the approximate locations of cross-strike structures of Kulander and Dean (1978), Pohn and others (1985), and Southworth (1986) (map sheet and fig. 6). They attributed these cross-strike features to subsurface lateral ramps. A density isopleth map of lineaments interpreted from Landsat MSS image data (Lang and others, 1985) shows the Lost River and Bergton gas fields located on lineament density highs (fig. 6). A fifth-degree lineament density isopleth map by Lang and others (1985) mimics the subsurface structure and also corresponds with the southern termination. In addition, a surficial cross-strike structure, initially interpreted by Lang (1982) to be a lateral ramp, approximately coincides with the location of the north end of a southern structural high in the subsurface Lower Devonian Oriskany (Lang and others, 1985). A southwest to northeast profile of depth to Oriskany from drill-hole data (Young and Harnsberger, 1955, Patchen, 1968), defines a broad northeast-dipping lateral ramp with over 3000 feet of relief between the Bergton and Lost River gas fields. South of the Bergton field, drill-hole depths to the Oriskany horizon define a southwest-dipping lateral ramp which is believed to be responsible for both the Parsons lineament and closure on the Bergton gas field (Simmons, 1983).

Pohn and others (1985) stated that the reason for "nearly mutual exclusivity of (Central Appalachian) gas fields and lateral ramps lie(s) in strike-slip movement along cross-strike basement faults, which underlie the lateral ramps... and gas which was originally present in the subsurface could have leaked out of the reservoirs through the shattered column of rock." Recent gas discoveries at intersecting CSD's (Patchen and others, 1985), which are attributed to lateral ramps, disputes this model. Fracture-porous CSD's containing gas sealed beneath an overriding thrust sheet suggests that slickensided faults may seal porous fractures (Gold and others, 1978). Likewise, differential movement along the CSD or lineament may have sealed porous and permeable fractures across strike, by slickensides and ductile shale flowage.

Additional fracture porosity and permeability targets associated with CSD's and lineaments include westward propagation of fractures, fractures in footwalls and hanging walls of tectonic and lateral ramps, and the juncture zone of fractures in a decollement with CSD fractures.

Conclusion

Cross-strike structures of the Appalachian Valley and Ridge and Plateau provinces are abundant and their mechanism of formation are varied. Although analysis of their origin is speculative in nature, some agreement exists. Five out of seven CSD's are attributed to the surficial expression of lateral ramps, and four of the seven CSD's may be related to passive involvement of the basement. Seventy-eight percent of lineaments are restricted to the cover rocks above basement while geophysical data suggest basement control on 22 percent. Thirty-two lineaments are interpreted to be the surficial expression of lateral ramps while 48 are interruptions in strike of structural and geomorphic features. The coincidence of lateral ramps with 32 percent of the lineaments and 70 percent of the CSD's suggests that lateral ramps may be more common in the Appalachians than suspected; lineaments and CSD's may reflect the surface expression of lateral ramps in the allochthonous cover rocks.

The use of CSD's and lineaments have been proposed for gas exploration in Devonian shales, based on the high fracture permeability expected (Wheeler, 1980), and recent gas discoveries in the Lower Devonian Oriskany Sandstone at intersecting CSD's (Patchen and others, 1985) supports this model. Tectonic transport associated with lateral ramps may contribute to structural closure on subsurface anticlinal traps of natural gas and subsequent sealing of the reservoir by shale flowage; areas adjacent to lineaments and CSD's may represent an exploration target.

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