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Topological constraints on imbricate thrust networks, examples from the Mountain City window, Tennessee, U.S.A.

F. A. Diegel

Department of Earth and Planetary Sciences, The Johns Hopkins University, Baltimore, MD 21218, U.S.A.

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Abstract—The geometry of thrust belts is best described in three dimensions as a network of linear geometric elements: trailing branch lines, where two thrusts diverge; leading branch lines, where two thrusts converge; tip lines, where thrust displacement vanishes; and cutoff lines, where a stratigraphic horizon intersects a thrust plane. There are a number of topological constraints in three dimensions on the interrelationship of these linear elements. These constraints provide a method of deciphering the three-dimensional structure of an area from the geologic map pattern alone if topography or structural culminations and depressions create significant structural relief.

The Mountain City window, Tennessee, is an example of an imbricate thrust network which reveals its topology on the map pattern because of the presence of culminations. The analysis of linear elements in this area allows the regional structural geometry to be described, and also two kinematically distinct types of imbricate thrust systems to be characterized; namely, hinterland- and foreland-dipping duplexes. The Doe Ridges culmination is a hinterland-dipping duplex, characterized by leading branch lines in a common roof thrust with the branch lines arranged in the same order, hinterland to foreland, as in the undeformed state. The Limestone Cove culmination is a foreland-dipping duplex, characterized by trailing branch lines in a common roof thrust with the branch lines reversed in order. Hinterland-dipping duplexes are the common and well known type. Foreland-dipping duplexes are formed by successive trailing branch lines moving up off the lower flat horizon onto the ramp at which the imbricate slices are formed.

INTRODUCTION

Branch lines, tip lines, and cutoff lines were defined by Boyer & Elliott (1982) who used them to discuss the geometry and kinematics of imbricate thrust networks in three dimensions. Elliott & Johnson (1980, figs. 13, 17 and 19) presented branch line and cutoff line maps showing the location of buried and eroded parts of the linear elements, to illustrate the shape of thrust sheets and duplexes of the Moine thrust belt in three dimensions. The Elliott & Johnson (1980) maps were constrained by surface data and balanced cross-sections. Hossack (1983) used branch line maps drawn from the geologic maps alone as constraints for a cross-section through the Scandinavian Caledonides, which resulted in a substantial reinterpretation of the regional structure. This paper is an extension of the earlier work as it examines the relationship of branch and tip lines with cutoff lines. The topology of the linear elements, which define a thrust network, can be deciphered systematically from detailed geologic maps and used to recognize different types of thrust systems.

In any particular area, two main factors determine the usefulness of this approach to deciphering thrust networks. First, the area must have a well-known stratigraphy finer than the scale of imbrication so that stratigraphic cutoff lines can be identified. Also, in order to use two-dimensional map data, the area must show significant structural relief on the scale of imbrication. This can be produced either by large topographic relief or by folding of the thrusts. The Mountain City window in northeast Tennessee is a complicated compound imbricate structure at the northwest edge of the Southern Appalachian Blue Ridge structural province. It consists of two culminations which have produced the necessary structural relief, revealing numerous branch, tip, and cutoff points on the map pattern (Figs. 1 and 2). Also, the imbricate thrusts ramp through a well known and carefully mapped lower Cambrian section (King *et al.* 1944, Lowry 1951, Rodgers 1953, King & Ferguson 1960, Bryant & Reed 1970, Rankin *et al.* 1972). This area will provide examples for the following discussion. Although the map of thrust traces in the Mountain City window area is complicated (Fig. 2), the faults appear to link up in patterns. To take advantage of this map information we must understand the three-dimensional topology of the linear elements which pierce the ground surface to produce branch, tip and cutoff points.

TOPOLOGICAL CONSTRAINTS

Tip lines and branch lines

Tip lines (Elliott 1976, Boyer & Elliott 1982, Hossack 1983) mark the extent of fault displacement in a way analogous to dislocations in crystals. Branch lines (Elliott & Johnson 1980, Boyer & Elliott 1982, Hossack 1983) are defined by the intersection of two fault surfaces. They are separated into two types: trailing branches if they represent lines where an imbricate thrust forms or leading branches where an imbricate thrust rejoins the original thrust to form a horse (Boyer & Elliott 1982, Hossack 1983). Figure 3 shows a major

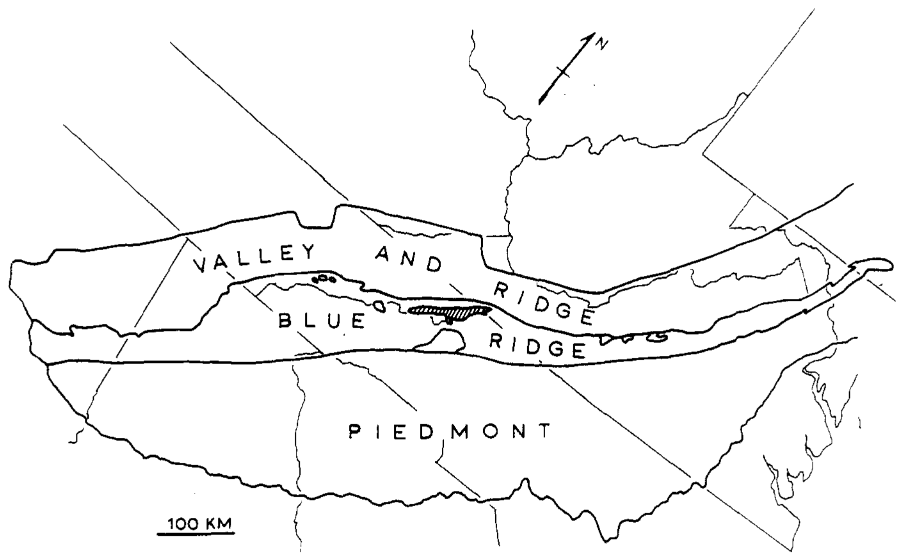

Fig. 1. Regional map showing location of the Mountain City window (shaded) at the northwestern edge of the Blue Ridge in Tennessee and North Carolina, U.S.A.

thrust with a small imbricate thrust beneath it bounded by a loop consisting of a trailing branch line and a tip line which pierces the erosion surface. Tips are constrained to either form a closed loop around an isolated fault, emerge at the synorogenic surface, or meet another fault surface at a branch line. These points of intersection are called the corners of the imbricate thrust (Boyer & Elliott 1982).

Continued growth of an imbricate thrust probably proceeds faster laterally than forwards as the branch line increases in length (Elliott 1976). If the imbricate thrust is forming at a ramp, the tip line may propagate towards an upper thrust, and if it rejoins the main thrust a leading branch line splits the tip line in two and forms a horse in cross-section (Fig. 4). Continued slip can result in the elimination of the tip lines altogether by joining of

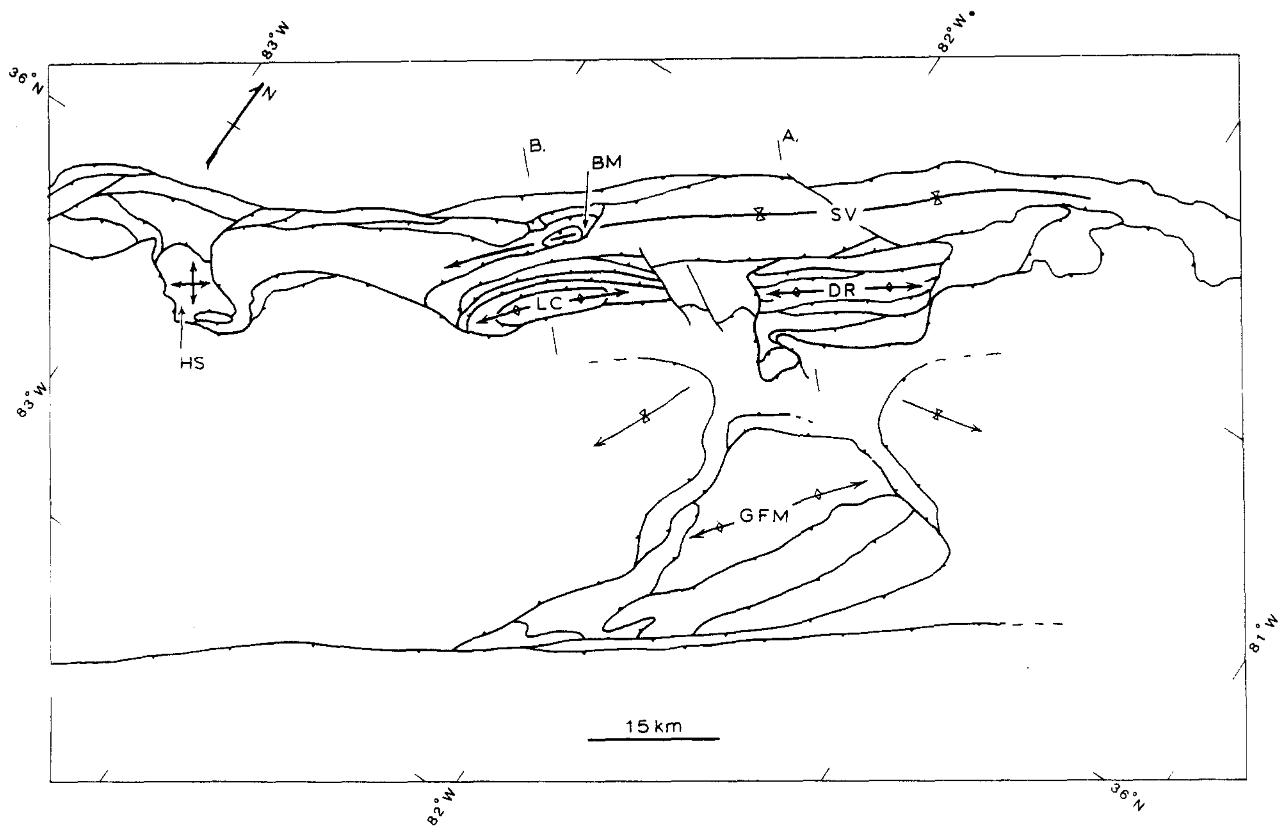

Fig. 2. Major thrust traces, culminations, depressions, and windows in the Blue Ridge thrust sheets of Tennessee and North Carolina. DR, Doe Ridges window; LC, Limestone Cove window; HS, Hot Springs window (Oriel 1950); BM, Buffalo Mountain thrust sheets; SV, Shady Valley thrust sheet; GFM, Grandfather Mountain window.

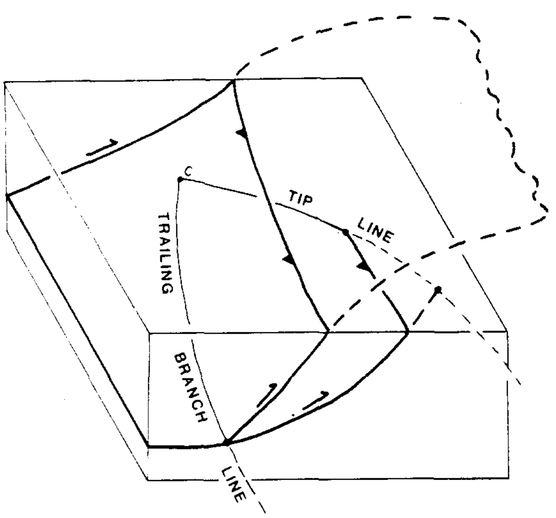

Fig. 3. Block diagram of a simple imbricate thrust. The tip line and trailing branch line meet at the corners of a splay. The top of the block represents the map section.

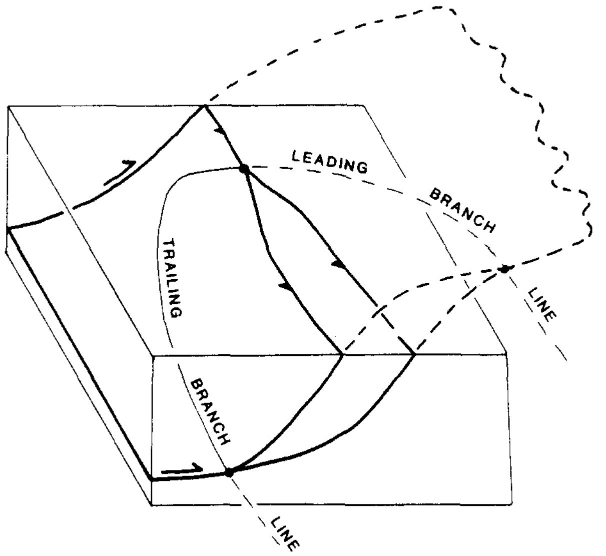

Fig. 5. Leading and trailing branches joined at a cusp to eliminate the tip line completely and form a loop of branch line which encloses the horse.

leading and trailing branches at a cusp (Boyer & Elliott 1982) to form a horse in three dimensions (Fig. 5). A fault surface is bounded, then, by branches and/or tips. Also, a three-dimensional horse is a lens of rock bounded by an upper and lower fault whose mutual branch line forms a closed loop defining the extent of the horse. Adjacent, overlapping horses have their branch-line loops crossing at points.

Cutoff lines

Cutoff lines are the intersection of a particular stratigraphic contact with a fault surface (Douglas 1958). Every fault surface has a matching hangingwall and footwall cutoff for each faulted stratigraphic horizon. Because, generally, thrusts cut up section in the direction of overthrusting, a single hangingwall or footwall cutoff line cannot form a closed loop (Dahlstrom 1970), but a hangingwall cutoff must either join the corresponding footwall cutoff of the same fault at a tip line or join the footwall cutoff of the structurally next highest fault at the branch line of the two faults (Figs. 6 and 7). In the case of a simple imbricate thrust with one tip and one branch, the hangingwall and footwall cutoffs of the imbricate thrust intersect at the tip line to form a loop which excludes the truncated bedding plane (Fig. 6). In the case of a horse, the hangingwall cutoff of the lower fault joins the footwall cutoff of the upper thrust at the branch lines to form a loop composed of two cutoff lines on the two faults which enclose the bedding plane within the horse (Fig. 7).

The relationships between the branch lines, tip lines and cutoff lines can be summarized as follows. (1) All (non-emergent) faults are bounded by tip lines, branch lines or a combination of both. (2) The tip line of an imbricate fault joins a branch line at points called corners. (3) Horses are rock masses bounded by a closed loop of branch lines which have leading and trailing

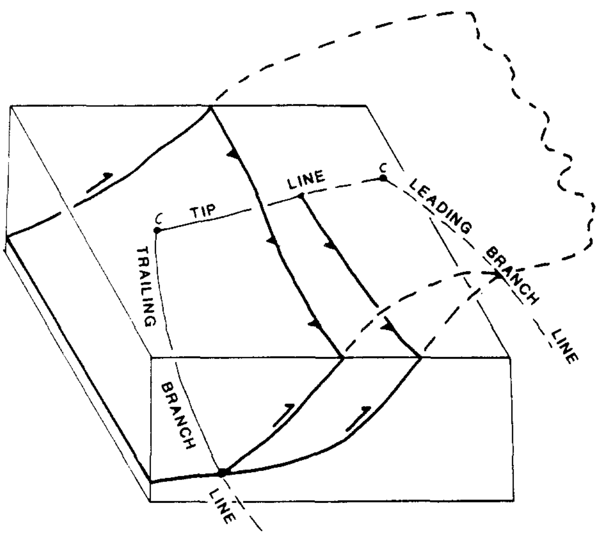

Fig. 4. Formation of a horse at a footwall ramp. The tip line of the splay has rejoined the main thrust at a higher glide horizon to form a leading branch line.

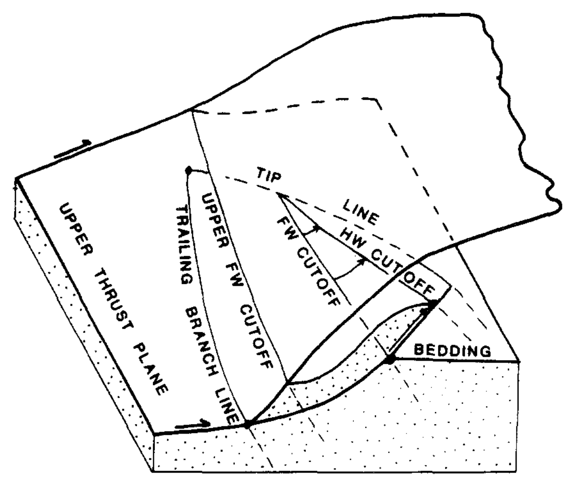

Fig. 6. Same block diagram as Fig. 3 showing a truncated stratigraphic horizon. The matching hangingwall and footwall cutoff lines separated by the fault join at the tip line.

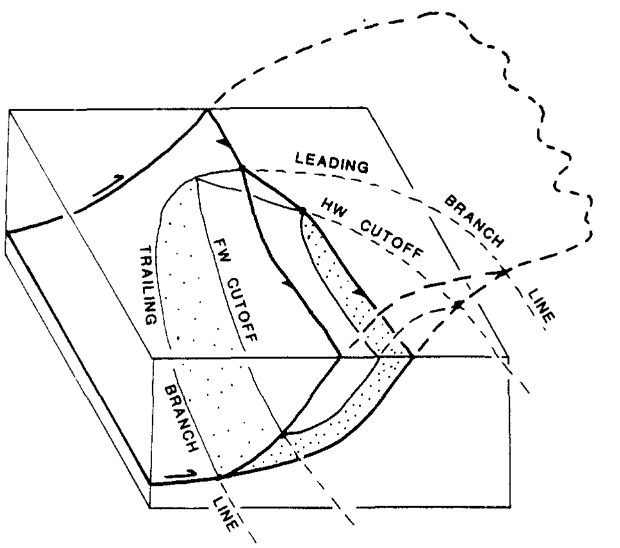

Fig. 7. Same block diagram as Fig. 5 showing a cutoff stratigraphic horizon. The hangingwall cutoff of the lower imbricate thrust joins the footwall cutoff of the upper thrust at the branch line.

segments joined at cusps. (4) Branch lines of overlapping slices cross at points. (5) Generally, thrusts have one hangingwall and one footwall cutoff for each faulted stratigraphic horizon. (6) Matching hangingwall and footwall cutoffs of a fault join at points on tip lines. (7) Within a horse the hangingwall cutoff of the lower thrust and the footwall cutoff of the upper thrust join at points on branch lines.

INTERPRETING THREE-DIMENSIONAL STRUCTURE FROM MAP PATTERNS

If imbricate fault structures plunge along strike, the branch lines, tip lines, and cutoff lines pierce the ground surface at tip points (Fig. 3), branch points (Fig. 5) and cutoff points (Fig. 7). In all of the preceding block diagrams (Figs. 3–7) a particular imbricate structure is considered, and the map pattern of branch, tip and cutoff points which results is illustrated on the top of each block. It is, of course, more important to reverse the procedure and be able to take a particular map pattern and deduce what kind of structure produced it. The seven topological constraints are independent of the erosion surface and plunge of the structure but the map pattern that a given structure produces is not (Fig. 8). Therefore, more information about the attitude of the linear elements at the ground surface is needed. Fortunately, two rules allow us to find the approximate orientation of cutoff lines and branch lines at their respective cutoff points and branch points.

Branch-line rules and the Little Pond Mountain thrust

Branch lines are expressed on maps or sections as points where three fault traces intersect. Thus three separate areas, thrust volumes in three dimensions, meet at a branch point. A branch line, however, forms a boundary to only a single volume as illustrated in Fig. 5.

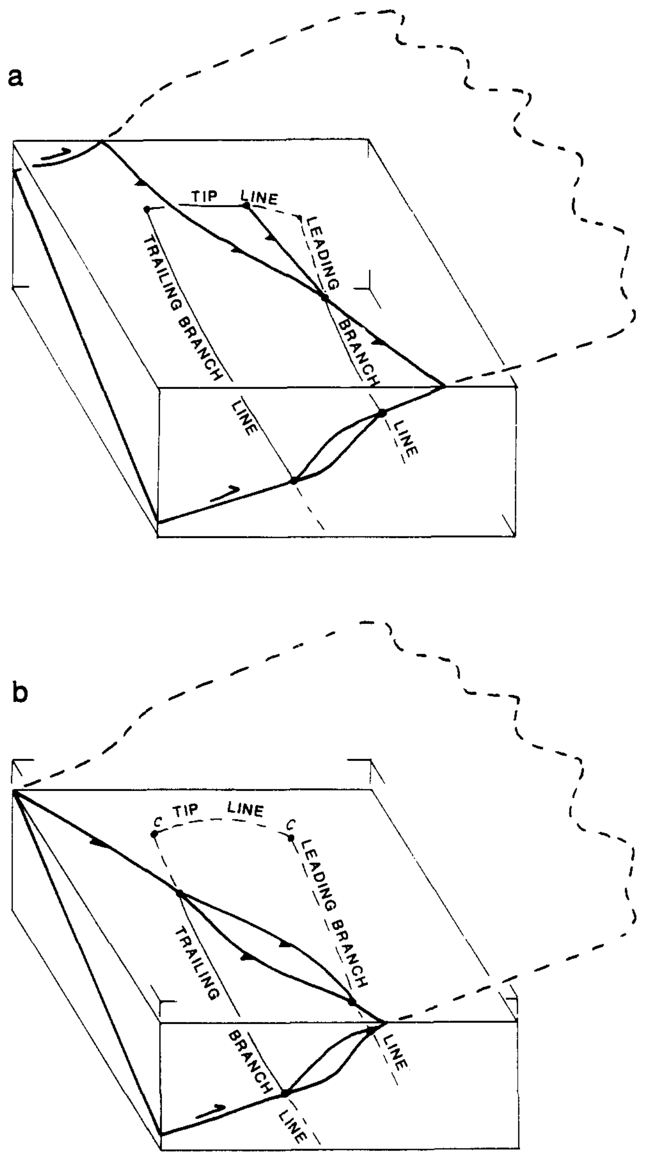

Fig. 8. Plunging horse showing different map expressions at a high (a) and low (b) erosion level.

Before we can determine the attitude of a branch line, we need to observe which of the three volumes meeting at a branch point is the one bounded by the branch line. Usually this is self evident from hangingwall and footwall relationships and the angles between thrust traces, but topography or folding of thrusts can modify the map pattern to obscure these relationships (left-hand side of Fig. 9). The bounded slice can be easily identified from the topology alone. This slice can be identified explicitly by recognizing that it is the only slice which is in the footwall of one slice and the hangingwall of the other. For example, in Fig. 9, slice B is the footwall of both A and C, and slice C is the hangingwall of both A and B, but slice A is the footwall of C and the hangingwall of B so that slice A is between the other two slices and is the slice bounded by the branch line. Topologically this is equivalent to a triple junction as shown on the right-hand side of the figure.

If a branch point lies in a lower horizon, the oldest formation in the slice, the branch is trailing and must plunge behind the slice which it bounds between the

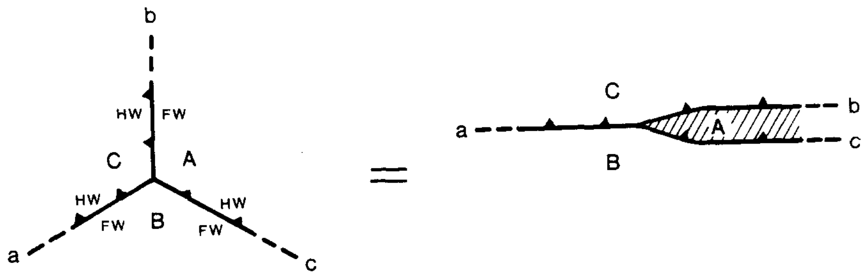

Fig. 9. Diagram to match the branch line (cropping out on a map at a branch point) with the slice to which it is a bounding branch line. See text for explanation.

movement direction and the trace of the upper thrust. If on the other hand the branch point lies in an upper glide horizon, the youngest formation in the slice, the branch is leading and must be eroded off in front of the slice and plunge between the movement direction and the trace of the thrust opposite the slice (Fig. 10). If the thrusts are dipping towards the foreland, then the rule is reversed. In this case a trailing branch line must be eroded off behind and above the slice and plunge between the movement direction and the thrust trace opposite the slice, and a leading branch line must plunge in front of the slice between the movement direction and the upper thrust trace (Fig. 10). This rule enables us to locate the branch point on cross-sections appropriately above or below the ground surface.

A good example from the Mountain City window comes from the trace of the Little Pond Mountain thrust (King & Ferguson 1960, Rodgers 1953) (Fig. 11). This thrust is folded around the Doe Ridges culmination, and, in fact, forms the boundary between the Doe Ridges imbricate structure of the northeast part of the window and the structurally higher southwest part of the window. The thrust has two branch points on the map. The southeast point lies in Precambrian crystalline basement, which is the oldest material involved in the thrusting. This point is the expression of the trailing branch line of the slice above the Little Pond Mountain thrust, and must plunge behind the slice to the southwest, and be eroded to the northeast. The northwest branch point is in the lower Cambrian Rome Formation, which is the upper detachment horizon throughout the Mountain City window. This point is the leading branch line, but because the thrust has been folded towards the foreland the branch line here also plunges to the southwest.

In terms of a horse, there are four possible map topologies of truncated stratigraphic horizons around branch points, and the branch-line rule enables us to determine the general attitude of the slice for each case (Fig. 12). If there are two leading branch points, then the erosion surface cuts the top of the horse. If there are two trailing branch points then the map is a section through the bottom part of the horse. If there is one leading and one trailing branch, the structure is a horse plunging towards the leading branch point. If the thrusts are rotated to a foreland-dipping attitude, the rule for locating branch lines is reversed (Fig. 12). The map of King & Ferguson (1960) shows examples of all of these types of map topologies among the smaller slices of the Doe Ridges structure (Fig. 11).

Cutoff-line rules and the Shady Valley thrust sheet

The rules for cutoff lines are analogous to those for branch lines. If thrusts cut up section in the direction of

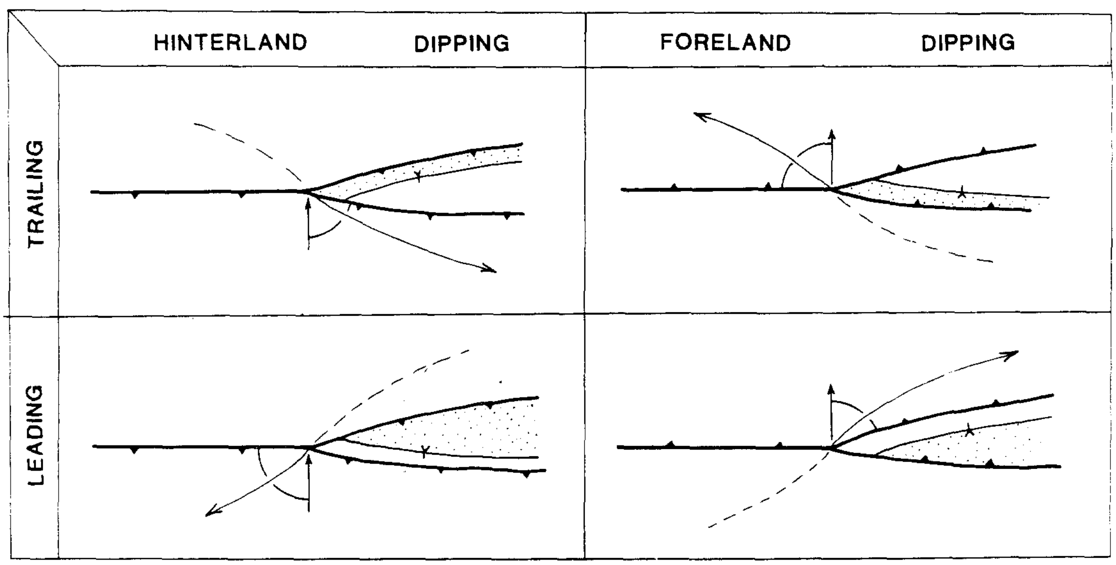

Fig. 10. Diagram illustrating the rule for locating branch lines above (dashed) and below (solid with arrow) the erosion surface. The rule is shown for leading and trailing branch lines in both hinterland- and foreland-dipping cases. Foreland is towards top of page. The stippled unit is older; the heavy arrow shows direction of overthrusting.

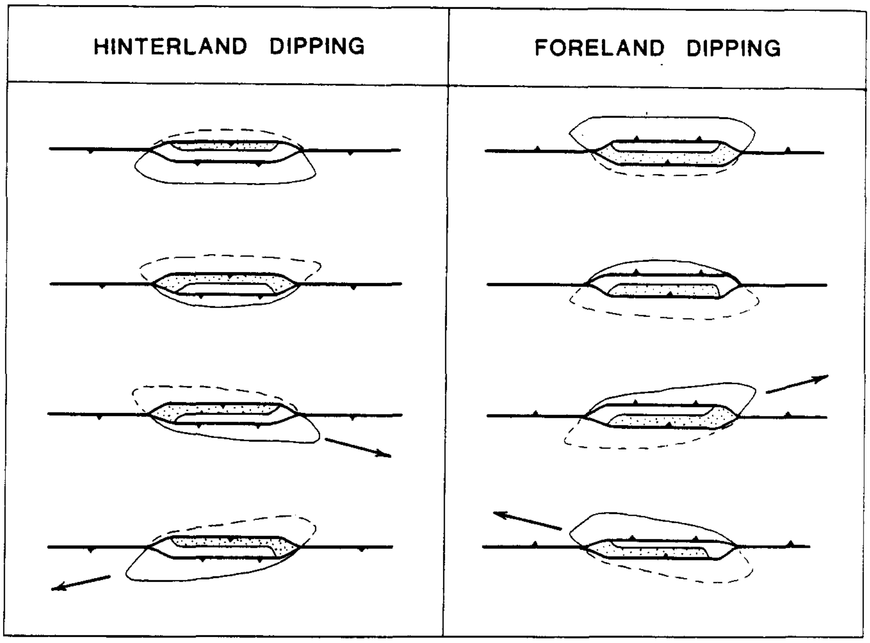

Fig. 11. Possible configurations of a stratigraphic contact within a horse and the attitude of the structure that each of these possibilities implies. Branch lines are dashed where eroded and solid where buried. The stippled unit is older; the foreland is towards the top of the page; arrows show direction of plunge for plunging horses.

slip then the buried part of a cutoff line on a hinterland-dipping thrust must plunge towards the younger side of the cutoff contact between the movement direction and the thrust trace. For a rotated thrust dipping towards the foreland, the buried portion of the cutoff lies on the older side of the cutoff contact between the movement direction and the thrust trace (Fig. 13).

A good example of the application of this rule is the cutoff line map for the contact of the Chilhowee Group and Shady Formation in the hangingwall of the Shady Valley thrust sheet just northwest of the Mountain City window (Fig. 14). This sheet is folded into the Stoney Creek Syncline so that the thrust intersects the ground surface twice (King & Ferguson 1960). On the northwest the Holston–Iron Mountain thrust dips towards the hinterland (southeast), but on the southeast the Mountain City culminations have rotated the thrust and related minor structures into a downward-facing, foreland-dipping position. The eroded and buried parts of the Chilhowee–Shady cutoff are sketched according to the rule above. This cutoff-line map shows the original irregular shape of the ramp of the Holston Mountain thrust through the Lower Cambrian section.

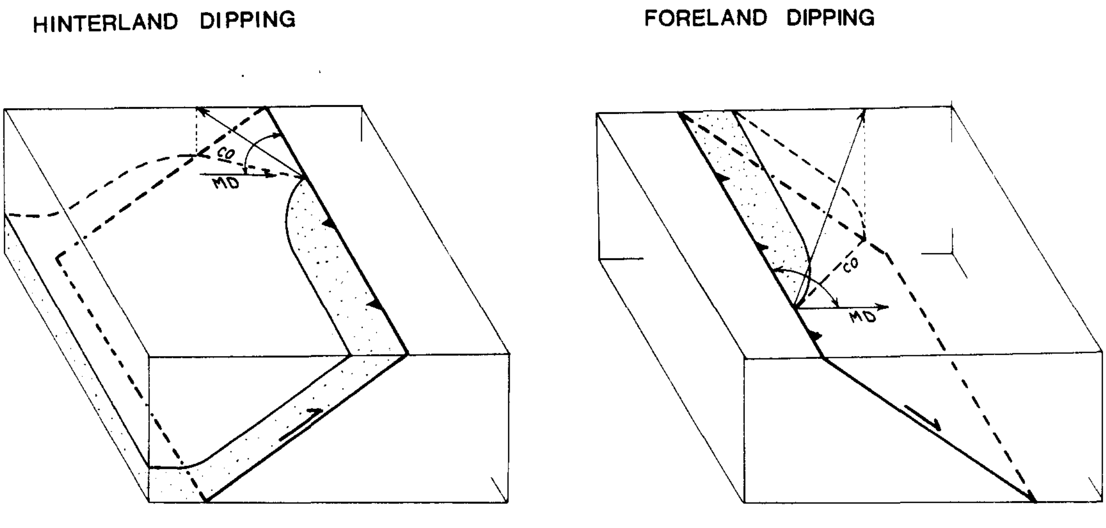

Fig. 12. Block diagrams illustrating rule for locating buried and eroded portions of cutoff lines. The top of the block is a map view. Stippled unit is older, and thrust motion is towards the right. If the thrust cuts up section in the direction of slip then in the hinterland-dipping case (left) the cutoff line (CO) must plunge down along the thrust plane, away from the older side of the cutoff point on the map, between the movement direction (MD) and the thrust trace. In the foreland dipping case (right) the cutoff line plunges towards the older side. The unlabelled arrow shows the projection of the plunging cutoff line onto the map.

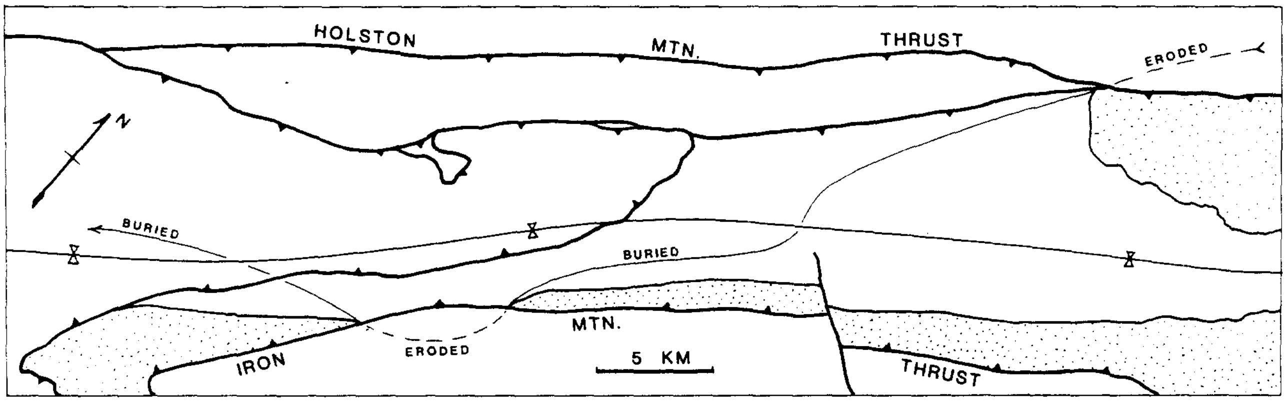

Fig. 13. Map of part of the Shady Valley thrust sheet showing buried and eroded parts of the Chilhowee–Shady cutoff line on the hangingwall of the Holston–Iron Mountain thrust. Chilhowee and older rocks stippled; Shady and younger formations unornamented.

CHARACTERIZING THRUST SYSTEMS

The geometric analysis described above can also be applied to groups of thrust slices and provides a way of characterizing the type of thrust system (as defined by Boyer & Elliott 1982) from the map pattern. For example the two culminations in the Mountain City window separated by the Little Pond Mountain thrust are both formed by thickening of the Lower Cambrian section by imbricate thrusting, but the topology of the map pattern reveals two fundamentally different geometries.

Hinterland-dipping structures—the Doe Ridges duplex

The Doe Ridges structure is a single large window through the folded thrust sheets of the Blue Ridge province cored by numerous imbricate thrusts which, where mappable, dip steeply southeast, hindwards, plac-

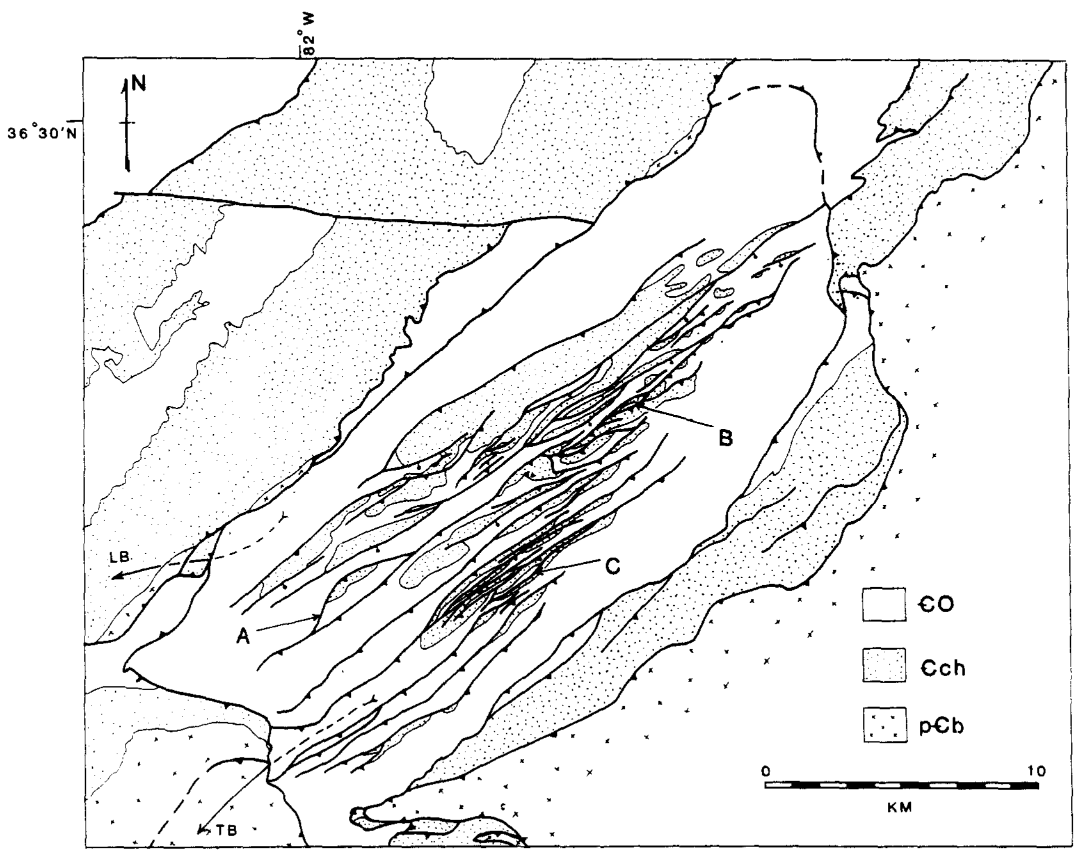

Fig. 14. Map of the Doe Ridges imbricate thrusts after King & Ferguson (1960) showing approximate position of buried (solid with arrow showing plunge) and eroded (dashed) portions of the leading and trailing branch lines of the Little Pond Mountain thrust slice. Map also shows the eroded top of a horse (A) with two leading branch lines at the surface; the eroded base of a horse (B) with two trailing branches at the surface; and a plunging horse (C) with a leading and a trailing branch line at the surface. PCb, Precambrian basement; Coh, Cambrian Chilhowee group; CO, younger Cambrian and Ordovician formations.

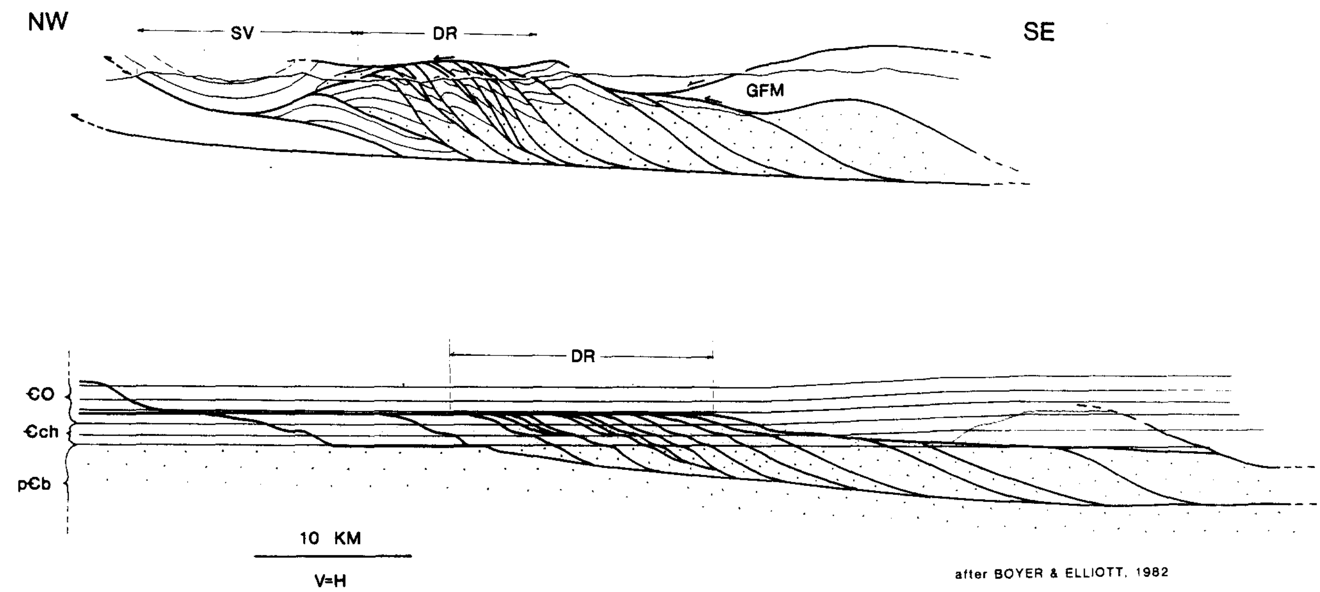

Fig. 15. Balanced cross-section through the Mountain City and Grandfather Mountain windows showing hinterland-dipping duplex structure formed at a major ramp from the basement through the Lower Cambrian Chilhowee group clastics to the Rome Formation (after Boyer & Elliott 1982). Trailing branch lines in the basement are on the floor thrust and leading branch lines in the Rome shales are on the roof thrust. The section is located as line A on Fig. 2. pCb, Precambrian basement; Coh, Chilhowee Group (Unicoi Formation and combined Hampton and Erwin Formations); CO, younger Cambrian and Ordovician formations (combined Shady and Rome Formations, Conasauga Group, Knox Group). SV, Shady Valley thrust sheet; DR, Doe Ridges imbricate slices; GFM, late Precambrian rocks of the Grandfather Mountain window.

ing older Chilhowee rocks on the younger Shady and Rome Formations (Fig. 11). Boyer & Elliott (1982) show a cross-section through this structure redrawn in part in Fig. 15. The thrusts lose stratigraphic separation along strike and are therefore difficult to map in this poorly exposed terrain, but thrusts observed in isolated outcrops between the end of the mappable parts of the thrusts and the trace of the roof thrust suggest that these imbricate thrusts branch with the roof thrust in the Rome shales. The loss of stratigraphic separation at the floor and roof of a duplex is a consequence of the kinematics of duplex formation (Boyer 1978). Also, at this relatively deep and internal position below the basement involved thrusts, a high degree of connectivity is to be expected (Boyer & Elliott 1982) and is shown by the presence of many leading branch points in the area.

The Rome Formation, being the youngest formation in the imbricate slices, is an upper glide horizon of the Mountain City imbricate structure; and the branch lines are leading branch lines that plunge away from the imbricate slices to the southwest along the roof thrust of the duplex. Trailing branch lines, probably in basement in the subsurface, lie in a floor thrust. Also, the slices are in the same order in the deformed and restored sections.

Foreland-dipping structures—the Limestone Cove duplex

The map pattern of the Limestone Cove imbricate system to the southwest (Fig. 16) is quite different from the Doe Ridges map, and this reflects the difference in the type of thrust system. First, the thrusts form five nested windows as each imbricate slice is folded into a foreland-dipping attitude. The thrusts still place older over younger rocks, but the branch points on the southwest side are in the older rocks of the section, the Sandsuck slates of the late Precambrian Ocoee Supergroup. Whereas hindward-dipping duplexes like the Doe Ridges structure are characterized by having leading branches in their roofs, the branch lines in the roof of the Limestone Cove structure are trailing branches. The branch-line rule is reversed for these foreland-dipping thrusts so that the trailing branch lines plunge away from the imbricate slices, off the southwest end of the culmination. Figure 17 is a cross-section through the Limestone Cove culmination showing the reversed branch lines. Higher slices are folded by lower and younger slices and the duplex is floored by the Little Pond Mountain thrust which outcrops to the northeast. This structure results from slip of trailing branch lines up onto the ramp past the location of the trailing branch of the subsequent slice.

Irregular imbricate structures

A third type of thrust system is characterized, not by a regular pattern of leading and trailing branch lines, but rather by crossing branch lines of an irregular structure. The three-dimensional geometry of these structures can be deciphered from complex map patterns using branch lines. A good example of an irregular imbricate structure comes from a published map of the Buffalo–Cherokee Mountain area, nestled into the syncline of the Shady Valley sheet northwest of the Limestone Cove structure (Fig. 18, after Ordway 1959). This area is composed of four main thrust slices which overlap laterally as well as across strike. Figure 18 shows a map of the thrust traces and the eroded and buried portions of the crossing branch lines.

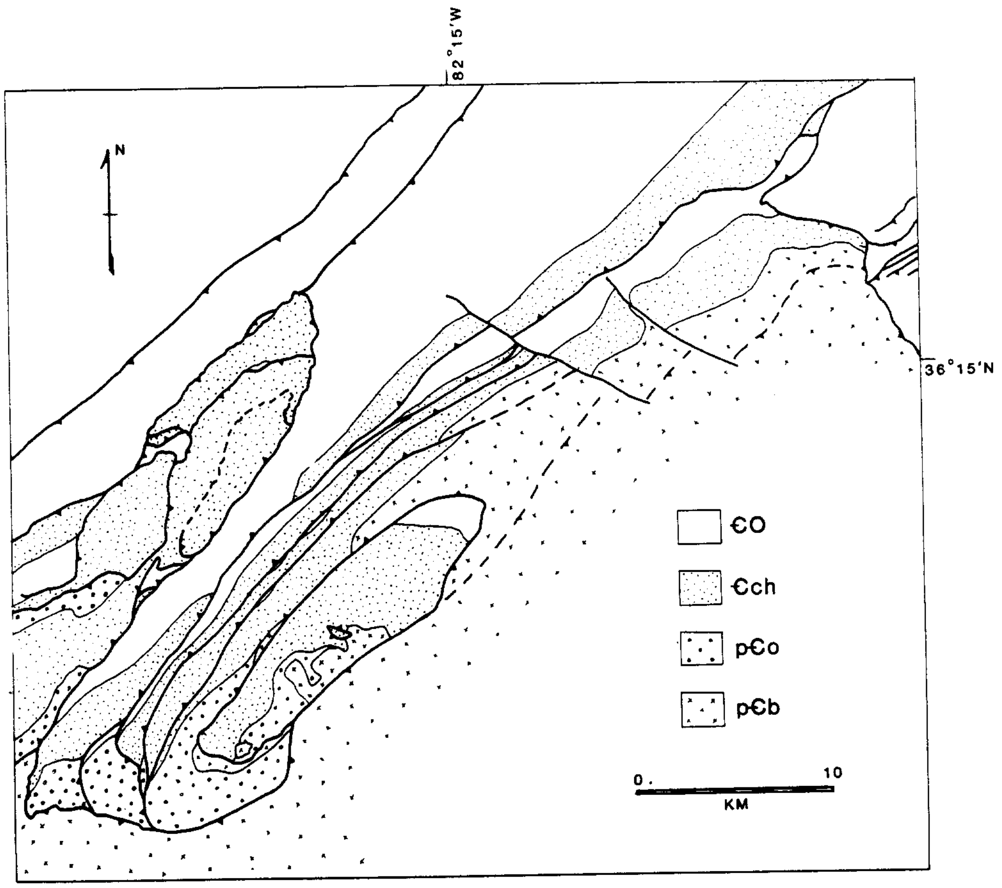

Fig. 16. Map of the Limestone Cove structure, modified from Rodgers (1953). PCb, Precambrian basement; pCo, Late Precambrian Ocoee Supergroup; Cch, Cambrian Chilhowee Group; CO, younger Cambrian and Ordovician formations.

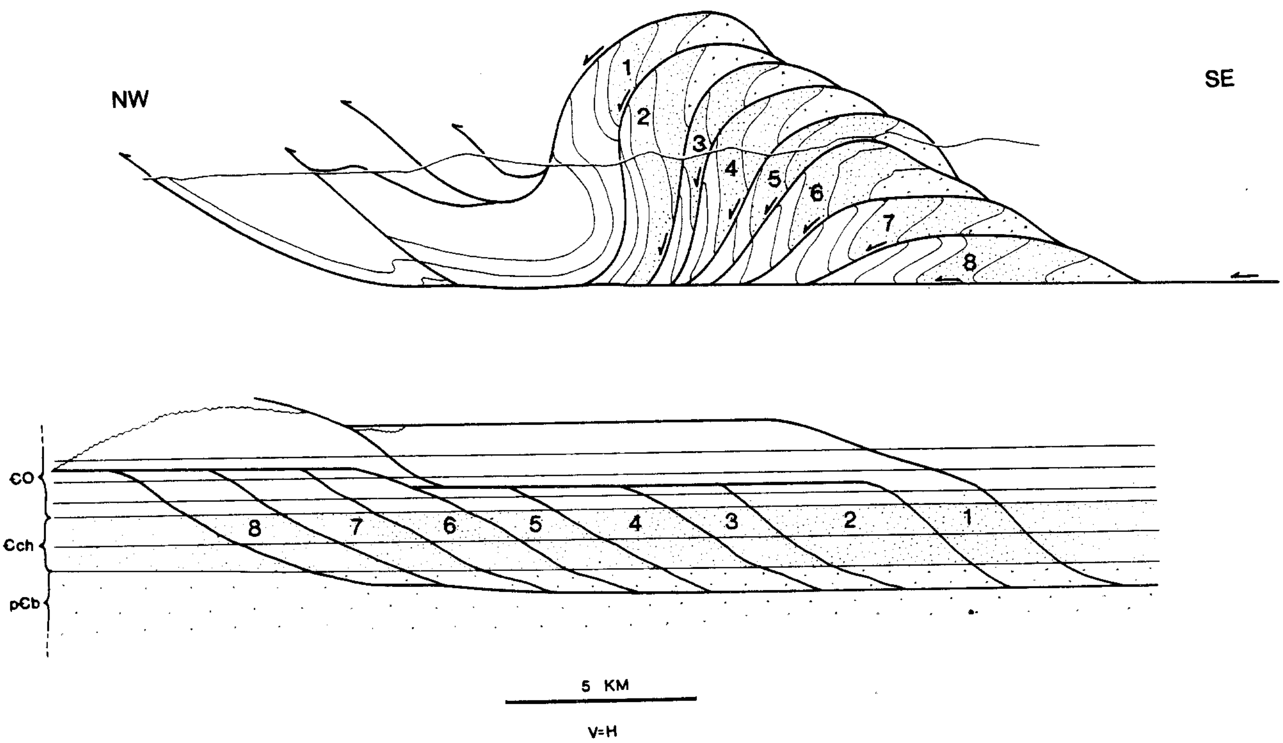

Fig. 17. Balanced cross-section through the Limestone Cove windows showing a forward-dipping duplex formed at the ramp through the Lower Cambrian section. The leading branch lines in basement lie on the floor thrust and the trailing branch lines in the Rome Formation and Conasauga Group lie on the floor thrust. The slices (1)–(8) formed in sequence towards the foreland. The higher and older slices are folded towards the foreland as each trailing branch line moves up the progressively collapsing ramp past the position of the subsequent trailing branch line. The section is located as line B on Fig. 2.

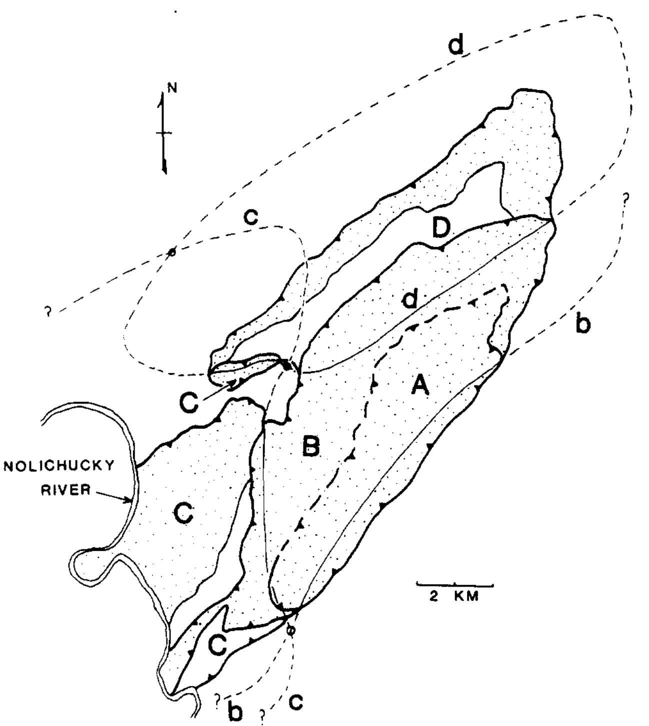

Fig. 18. Map of crossing branch lines in the Cherokee–Buffalo Mountains area. Branch lines solid where buried and dashed where eroded. Branch lines labelled b, c, and d enclose horses B, C, and D, respectively. Note that it is not immediately apparent that the three southwestern branch points of branch line d are associated with slice D.

There are two orders of application of this branch line analysis. It has been shown how individual thrust systems can be identified and characterized in terms of their branch lines. The same principles that have been described for individual thrust slices are also applicable to the branch lines of major sheets which may themselves be composed of imbricate systems. The application to groups of slices can be used to work out regional geometry; that is, how different thrust systems and major sheets are related in three dimensions.

LATERAL TERMINATIONS

In the foregoing discussion, it has been implicitly assumed that all branch lines are either leading or trailing and that branch lines lie consistently in easily identifiable glide horizons. In two dimensions, for duplex structures with well-developed glide horizons like the Doe Ridges and Limestone Cove examples, this approach has been sufficient; but the real advantage of considering the geometry of branch lines is that they describe the three-dimensional shape and position of fault slices.

There are essentially three ways a horse can end laterally: at a tip line and two corners (Fig. 4), at a branch line with a cusp (Fig. 5), or at a tear fault or lateral ramp where the branch line will have a lateral segment parallel to the slip direction (Hossack 1983). Lateral branch lines are not constrained to lie within the upper or lower glide horizons. Similarly, where a horse ends at a cusp, for some distance the branch lines must cross all of the stratigraphy within the slice.

This complicates identification of branch lines on maps. If a branch line is not clearly at an upper or lower glide horizon, it could be either a leading, trailing or lateral branch line; but the relative level in the stratigraphy of the two branch points of a horse on a map is an indication of the plunge of the horse. This relationship will break down if the horse has formed obliquely to the stratigraphy; that is, if there are no consistent glide horizons being followed by the thrusts. In that case the leading and trailing branch lines transect the stratigraphy.

In general, lateral branch lines may be recognized by the orientations of minor structures measured in the field, or by calculation of the orientation of cutoff lines from the orientations of bedding and the fault plane. In some instances lateral branch lines are easily recognizable from map patterns. Consider the case of a horse being plucked from a ramp with a steep lateral segment. This lateral ramp can be thought of as a distinct tear fault which intersects the imbricate thrusts. These intersections are lateral branch lines, one with the upper thrust and one with the lower thrust which join at the trailing and leading branch lines. If the horse is thrust onto a flat, then there are two possibilities. The lateral ramp can be folded over, as must happen to gently dipping tears, in which case the lower branch line becomes unrecognizable, the tear fault being folded into parallelism with the imbricate thrust. Or it can retain its steep orientation while offsetting higher older sheets.

An example of a lateral ramp occurs at the northeast end of the Limestone Cove duplex which ends abruptly at a steep cross fault (Fig. 16). The southwest side of the horses terminate in branch lines in late Precambrian slates of the Ocoee Group. On the northeast side, where the Lower Cambrian quartzites lie directly upon the unconformity with crystalline basement, the horses end at two major cross faults. There are at least five sheets on the SW side of the cross fault and only one on the northeast. The older Holston–Iron Mountain roof thrust is offset by the cross fault, which tips out in that sheet, to accommodate the loss of extra section created by the Limestone Cove imbricate slices. This fault then is in part a hangingwall lateral ramp or tear fault but also a hangingwall drop fault (Butler 1982).

DISCUSSION

Although much can be learned about three-dimensional structures using the linear elements as they are expressed on geologic maps; the method, requiring structural relief and correct detailed mapping, is not always reliable. Thrusts do sometimes cut down section, but because this has been demonstrated to be uncommon (see Boyer & Elliott 1982 for a review) this interpretation should be avoided unless there is independent evidence supporting it. Likewise, thrusts can also cut older faults. This can happen even in a foreland progression (Butler 1983). This interpretation is tenable only if there are matching truncations analogous to stratigraphic cutoff lines on either side of the younger fault.

Essentially, this approach to interpreting maps is the application of a model of foreland-progressing branching and rejoining imbricate thrusts. It is useful in that this model has been shown to have wide application in the Appalachians, the Alps, and in the Rockies (reviewed by Boyer & Elliott 1982 with subsequent contributions in the Scandinavian Caledonides by Hossack 1983, and the Alps by Butler 1983), and that it can act as a test of the assumption of strict foreland progression. A further test of a particular interpretation is given by the orientation of small-scale structures consistent or inconsistent with the interpretation. Also, since this approach is topological, a more complete description, in three dimensions of the locations of the linear elements, faults, and contacts must be constrained by surface orientation data, and where possible, by subsurface and geophysical data compiled downplunge onto compatible serial balanced cross-sections, guided by the topology indicated by the linear elements.

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