Glossary of thrust tectonics terms

K.R. McClay

Department of Geology, Royal Holloway and Bedford New College, University of London, Egham, Surrey, England, TW20 0EX

This glossary aims to illustrate, and to define where possible, some of the more widely used terms in thrust tectonics. It is presented on a thematic basis - individual thrust faults and related structures, thrust systems, thrust fault related folds, 3-D thrust geometries, thrust sequences, models of thrust systems, and thrusts in inversion tectonics. Fundamental terms are defined first, followed by an alphabetical listing of related structures. Where appropriate key references are given.

Since some of the best studied thrust terranes such as the Canadian Rocky Mountains, the Appalachians, the Pyrenees, and the Moine thrust zone are relatively high level foreland fold and thrust belts it is inevitable that much of thrust tectonics terminology is concerned with structures found in the external zones of these belts. These thrustbelts characteristically consist of platform sediments deformed by thrust faults which have a ramp-flat trajectories (Bally *et al.* 1966; Dahlstrom 1969, 1970; Price 1981; Rich 1934; and others). Steps in the thrust surface generate geometrically necessary folds in the hangingwall above (Fig. 1). Therefore much attention has been focussed upon hangingwall deformation in thrust belts and upon conceptual and geometric models to explain them.

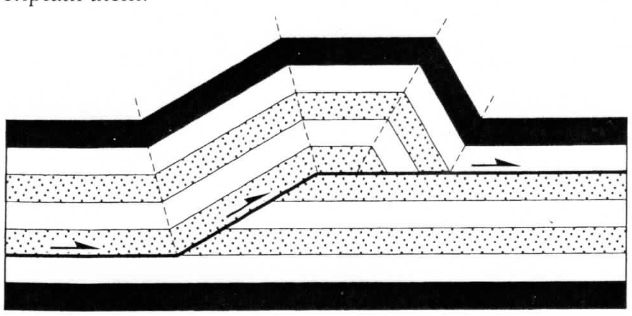

Figure 1. Idealised thrust fault showing kink band style folding in the hangingwall and no deformation in the footwall.

Many of the illustrations used in this glossary have been constructed using the programme *FaultII*™ (Wilkerson & Associates) that gives kink band geometries (e.g. Suppe 1983, 1985; Mitra 1986, 1990), commonly found in shallow thrustbelts. This, however, is not meant to imply that kink-band folding is the only geometric style found in high level thrustbelts (see Ramsay 1991, this volume). This glossary is not meant to be exhaustive but attempts to cover many of the terms used in the papers presented in this volume and those of thrust tectonics literature in general. The reader will recognise the difficulty in precisely defining many of the terms used in thrust tectonics as individual usages and preferences vary widely.

Thrust faults

Thrust fault: A contraction fault that shortens a datum surface, usually bedding in upper crustal rocks or a regional foliation surface in more highly metamorphosed rocks.

This section of the glossary defines terms applied to individual thrust faults (after McClay 1981; Butler 1982; Boyer & Elliott 1982; Diegel 1986).

Backthrust: A thrust fault which has an opposite vergence to that of the main thrust system or thrust belt (Fig. 2). Backthrusts are commonly *hinterland-vergent thrusts.*

Figure 2. Backthrust showing an opposite sense of vergence to that of the foreland vergent thrust system.

Blind thrust: A thrust fault that is not emergent - i.e. it remains buried such that the displacement on the thrust below is compensated by folding or cleavage development at a structurally higher level (Fig. 3) (cf. Thompson 1981).

Figure 3. Blind thrust system formed by a buried imbricate fan in which the overlying strata are shortened by folding.

Branch line: The line of intersection between two thrust sheets (Fig. 4a). For duplexes there are *trailing edge branch lines* and *leading edge branch lines* (see duplexes below). See Diegel (1986) for a full discussion of branch lines.

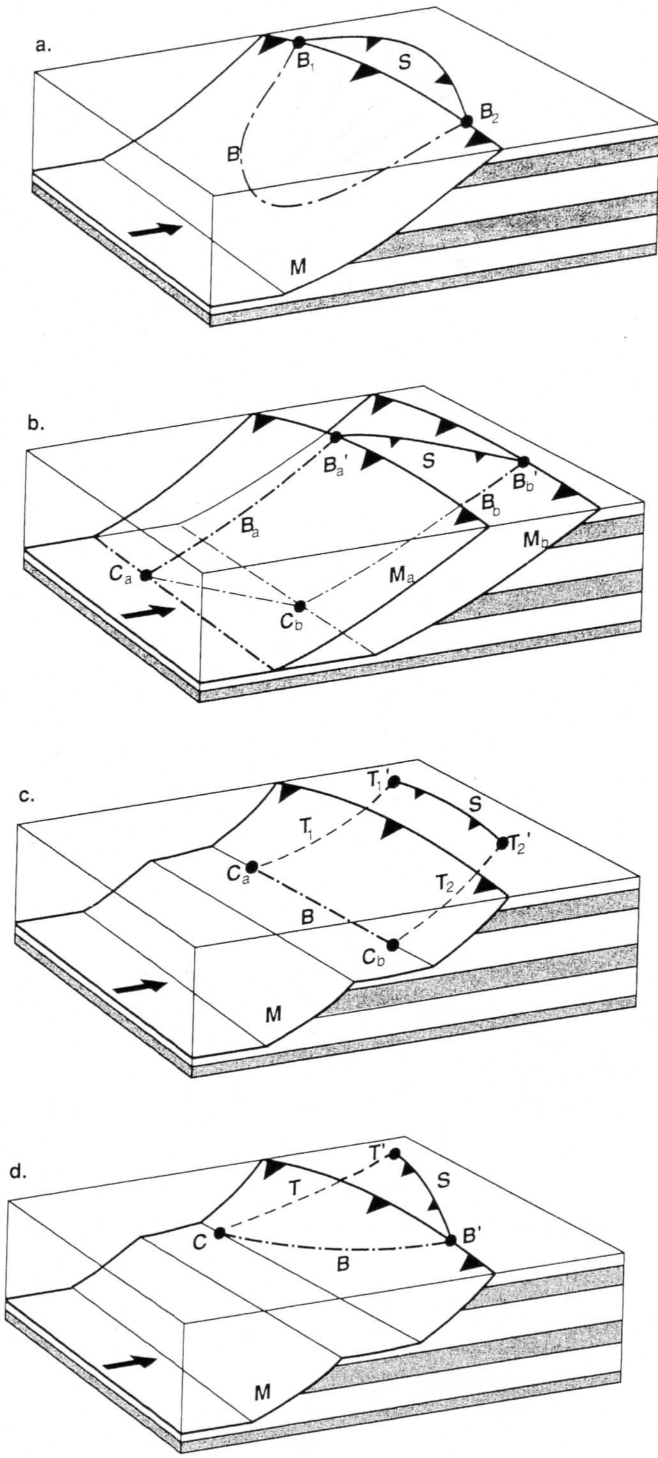

Figure 4. Thrust imbricates and splays showing branch lines, branch points and tip lines (adapted after Boyer & Elliott 1982). **(a)** *Rejoining imbricate* or *rejoining splay* **S** joins the *main fault* **M** along the *branch line* **B** which intersects the surface at two branch points B_1 and B_2. **(b)** *Connecting imbricate* or *connecting splay* **S** which joins two *main faults* M_a and M_b along *branch lines* B_a and B_b. There are two *branch points* B_a' and B_b' and two *corners* C_a and C_b. **(c)** *Isolated imbricate* or *isolated splay* **S** which intersects the *main fault* **M** along a *branch line* **B**. *Tip lines* T_1 and T_2 define the ends of the splay **S**. *Tip lines* T_1 and T_2 meet *branch line* **B** at *corners* C_1 and C_2. The *tip lines* intersect the surface at *tip points* T_1' and T_2'. **(d)** *Diverging imbricate* or *diverging splay* **S** intersects the *main fault* **M** along *branch line* **B**. The *branch line* **B** has one *corner* **C** and a *branch point* **B'** where it intersects the surface. The *tip line* **T** has one *corner* **C** and a *tip point* **T'** where it intersects the surface.

Branch point: The point of intersection between a branch line and the erosion surface (Fig. 4b). The term *branch point* is also used in cross-section analysis for the point where the branch line intersects the plane of the cross-section - i.e. in this context it is the 2D equivalent of a branch line (Fig. 5).

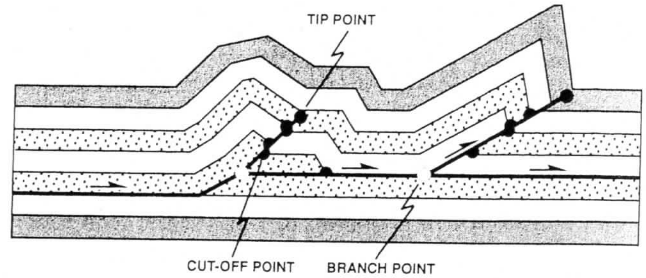

Figure 5. Cross-section illustrating branch points (white circles), cut-off points (black half-moons) and tip-points (black circles).

Cut-off line: The line of intersection between a thrust surface and a stratigraphic horizon (Fig. 6).

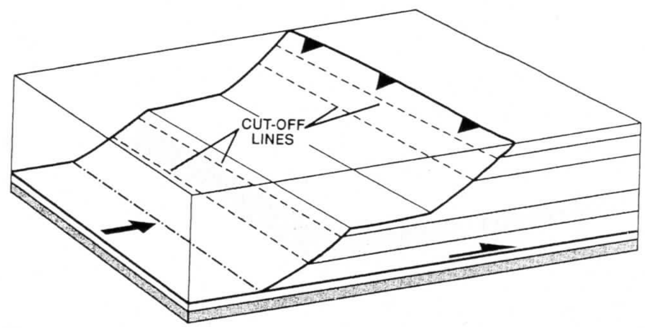

Figure 6. Footwall cut-off lines.

Cut-off point: The point of intersection between a cut-off line and the erosion surface. The term *cut-off point* is also used in cross-section analysis for the point where the cut-off line intersects the plane of the cross-section - i.e. in this context it is the 2D equivalent of a cut-off line (Fig. 5).

Emergent thrust: A thrust fault that emerges at the erosion surface.

Flat: That part of a thrust fault which is bedding parallel or parallel to a regional datum surface (cf. a regional foliation in metamorphic rocks) (Fig. 7).

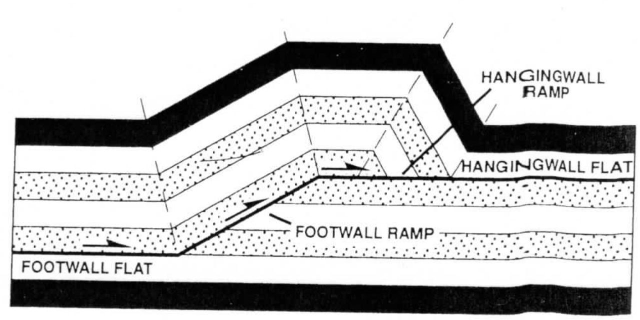

Figure 7. Thrust ramps in cross-section.

Footwall cut-off lines are the lines of intersection between a thrust surface and a stratigraphic horizon in the footwall of thrust (Fig. 6) (Diegel 1986).

Footwall cut-off point: The point of intersection between a cut-off line in the footwall of the thrust and the erosion surface.

Footwall flat: That part of the footwall of a thrust fault where the thrust fault is bedding parallel or parallel to a regional datum surface (cf. a regional foliation in metamorphic rocks) (Fig. 7).

Footwall shortcut thrusts: A low angle thrust fault developed in the footwall of a steep thrust fault (Fig. 8). The resultant lower angle fault trajectory is kinematically and mechanically more feasible for large displacement than the high angle fault trajectory (see Knipe 1985; McClay & Buchanan 1991, this volume)

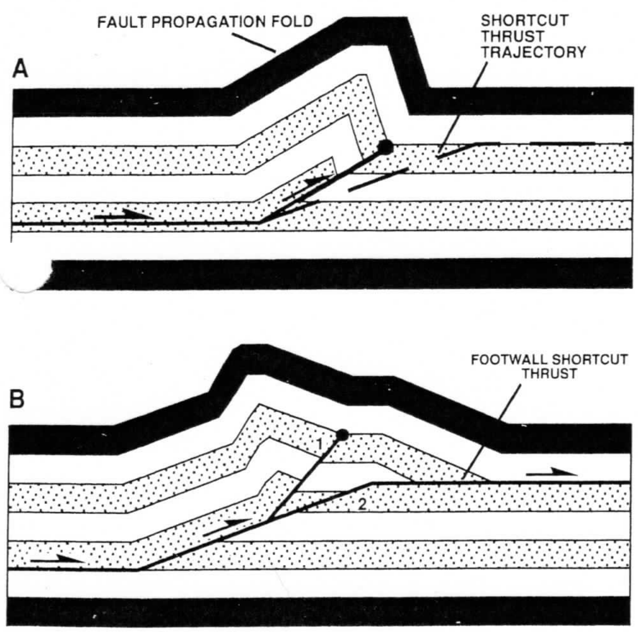

Figure 8. Footwall shortcut thrust. (**a**) Fault propagation fold with trajectory of incipient footwall shortcut thrust. (**b**) Final configuration after displacement on the footwall shortcut thrust.

Foreland-vergent thrust: A thrust fault that verges towards the undeformed foreland of the thrust belt (Fig. 9).

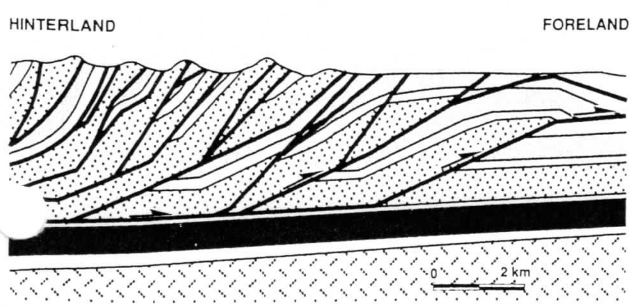

Figure 9. Foreland-vergent thrust system.

Frontal ramp: A ramp in the thrust surface that is perpendicular to the direction of transport of the thrust sheet (Fig. 10). Ramp angles are commonly between 10° and 30°.

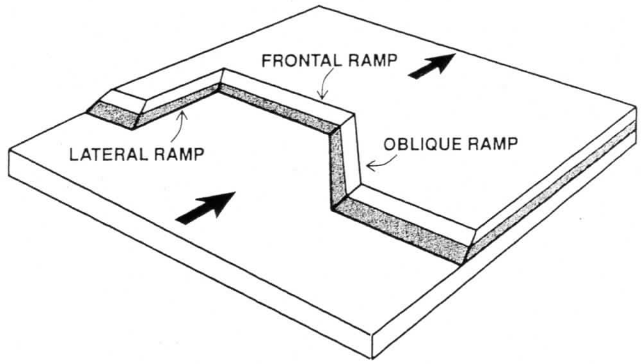

Figure 10. 3D thrust footwall ramp structures.

Hangingwall cut-off lines: The lines of intersection between a thrust surface and a stratigraphic horizon in the hangingwall of the thrust.

Hangingwall cut-off point: The point of intersection between a cut-off line in the hangingwall of the thrust and the erosion surface.

Hangingwall flat: That part of the hangingwall of a thrust fault where the thrust fault is bedding parallel or parallel to a regional datum surface (cf. a regional foliation in metamorphic rocks) (Fig. 7).

Hinterland-vergent thrust: A thrust fault that verges towards the hinterland of the orogen (i.e away from the undeformed foreland).

Klippe: An isolated portion of a thrust nappe or thrust sheet that is separated from the main part of the thrust nappe or thrust sheet as a result of erosion (Fig. 11).

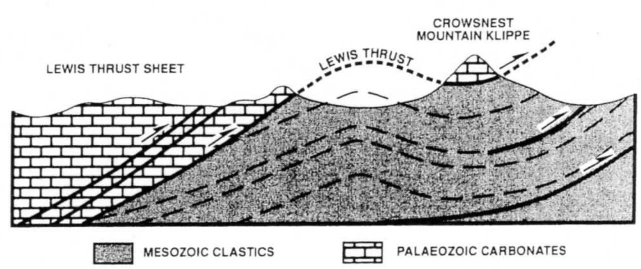

Figure 11. Klippe (adapted after McClay & Insley 1986).

Lateral ramp: A ramp in the thrust surface that is parallel to the direction of transport of the thrust sheet (Fig. 10). Ramp angles are generally between 10° and 30°. (Note that if the lateral structure is vertical then it becomes a thrust transport parallel tear or strike-slip fault and should not be termed a lateral ramp).

Listric thrust fault: A concave upwards thrust fault such that the upper section is a steep high angle contraction fault, the middle section is a medium angle contraction fault and the sole is a bedding plane parallel fault (Fig. 12).

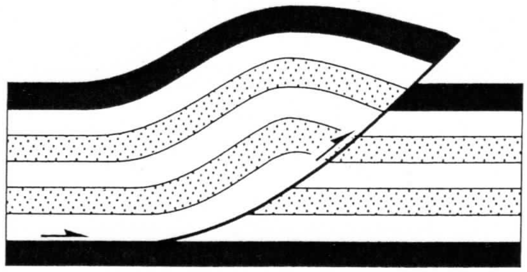

Figure 12. Listric thrust fault.

Oblique ramp: A ramp in the thrust surface that is oblique to the direction of transport of the thrust sheet (Fig. 10). Ramp angles are generally between 10° and 30°.

Out of the graben thrusts: Thrust faults that propagate outwards from a graben structure as a result of the contraction and inversion of a pre-existing extensional structure (Fig. 13) (see McClay & Buchanan 1991, this volume).

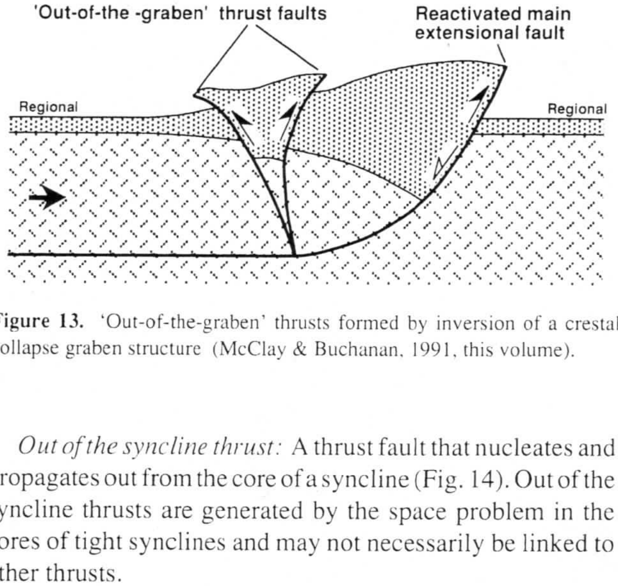

Figure 13. 'Out-of-the-graben' thrusts formed by inversion of a crestal collapse graben structure (McClay & Buchanan, 1991, this volume).

Out of the syncline thrust: A thrust fault that nucleates and propagates out from the core of a syncline (Fig. 14). Out of the syncline thrusts are generated by the space problem in the cores of tight synclines and may not necessarily be linked to other thrusts.

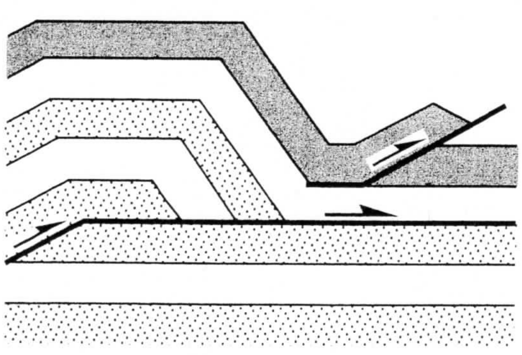

Figure 14. 'Out-of-the-syncline' thrust.

Pop -up: A section of hangingwall strata that has been uplifted by the combination of a foreland vergent thrust and a hinterland vergent thrust (Fig. 15).

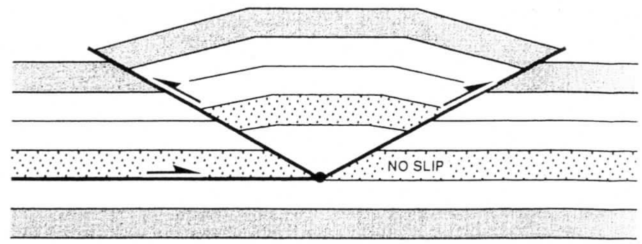

Figure 15. 'Pop-up' structure.

Ramp: That part of a thrust fault that cuts across bedding (or the appropriate datum plane-see above) (Fig. 7). Ramps may be divided into *hangingwall ramps* and *footwall ramps* (Fig. 7). Ramps commonly have angles between 10° and 30°.

Regional: The regional is the elevation of a particular stratigraphic unit or datum surface where it is not involved in the thrust related structures (Fig. 16). For thrust faults / contraction faults the hangingwall is elevated above regional and there is shortening of the datum plane such that the well in Figure 16 intersects a repeated section of bed A.

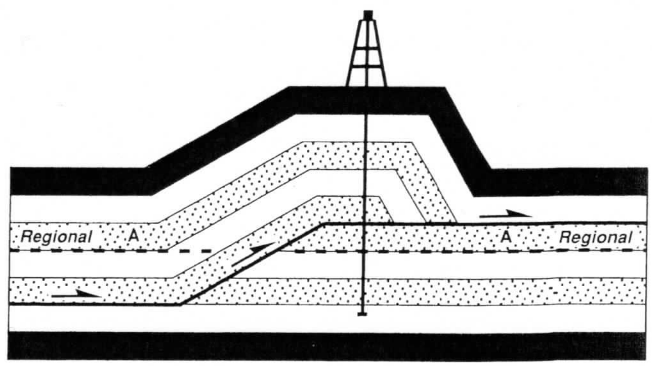

Figure 16. The concept of "regional" for bed A in a simple thrust structure.

Smooth trajectory thrust: A thrust fault with a trajectory that is smoothly varying and does not have a staircase form (Fig. 17). Smooth trajectory thrusts are found in higher grade metamorphic rocks (Cooper & Trayner 1986; McClay 1987) where ductile penetrative strains are developed within the thrust sheet.

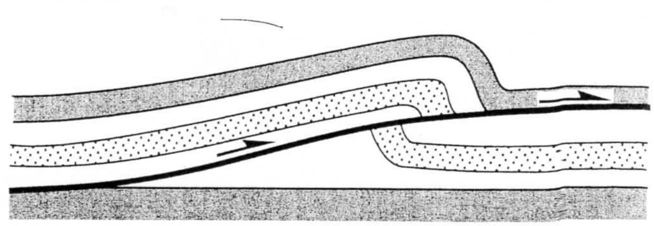

Figure 17. Smooth trajectory thrust.

Sole thrust: The lowermost thrust common to a thrust system (may also be termed a *floor thrust* - see thrust systems below).

Splay: A secondary thrust fault (i.e. smaller in size and displacement) that emerges from a main thrust fault. Boyer & Elliott (1982) define four types of splays (Fig. 4).
Rejoining splay (Fig. 4a), *Connecting splay* (Fig. 4b), *Isolated splay* (Fig. 4c), *and Divergent splay* (Fig. 4d).

Thrust nappe: A large thrust sheet which may have been generated from a recumbent fold in which the lower limb has been faulted out to form the sole thrust of the nappe (Fig. 18). Thrust nappes may also be generated from detachment thrusting and from inversion structures (cf. from inversion of ramp-flat extensional fault systems - see McClay & Buchanan 1991, this volume).

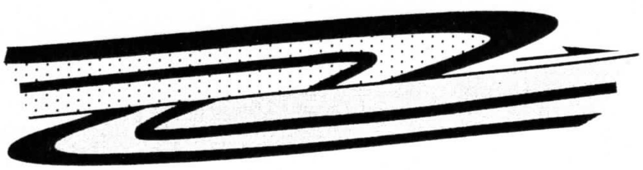

Figure 18. Thrust nappe developed by thrusting out the lower limb of a recumbent overfold.

Thrust sheet: A volume of rock bounded below by a thrust fault.

Thrust trajectory: The path that the thrust surface takes across the stratigraphy (often displayed on cross sections and restored sections). In high-level foreland fold and thrust belts thrust faults are commonly described as having *staircase* or *stair-step* trajectories (Fig. 19) typically with long bedding-parallel fault surfaces (*flats*) separated by shorter, high-angle fault segments that cut across the bedding (*ramps*).

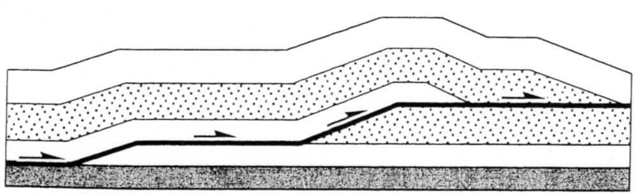

Figure 19. Staircase thrust trajectory consisting of ramps and flats.

Thrust vergence: The direction towards which the hangingwall of the thrust fault has moved relative to the footwall.

Tip line: The edge of a thrust fault where displacement dies to zero (Fig. 4c).

Tip point: The point of intersection between a tip line and the erosion surface (Fig. 4c). The term *tip point* is also used in cross-section analysis for the point where the tip line intersects the plane of the cross-section - i.e. in this context the tip point is the 2D equivalent of a tip line (Fig. 5).

Thrust systems

Thrust system: A zone of closely related thrusts that are geometrically, kinematically and mechanically linked.

This section of the glossary deals with *linked* thrust faults that form thrust systems. The terminology for thrust systems stems from Dahlstrom (1970), Boyer & Elliott (1982), Mitra (1986) and modified by Woodward *et al.* (1989). Thrust systems include duplexes, imbricate thrust systems and triangle zones (Fig. 20 - next page).

Duplexes

Duplex: An array of thrust horses bounded by a *floor thrust* (i.e. sole thrust) at the base and by a *roof thrust* at the top (Figs 20 & 21).

The stacking of the horses and hence the duplex shape depends upon the ramp angle, thrust spacing, and displacement on individual link thrusts. Models for duplex formation (Boyer & Elliott 1982; Mitra 1986) generally assume a 'forward-breaking' thrust sequence (see *thrust sequences* below). Mitra (1986) revised Boyer & Elliott's (1982) classification of duplexes and proposed a threefold classification (Fig. 21) consisting of -

1) Independent ramp anticlines and hinterland sloping duplexes (Fig. 21a);
2) True duplexes (Fig. 21b);
3) Overlapping ramp anticlines (Fig. 21c).

For independent ramp anticlines the final spacing between the thrusts is much greater than the displacement on the individual thrusts and the structure formed consists of independent ramp anticlines separated by broad synclines (Fig. 21a). Hinterland sloping duplexes (Fig. 21a) are formed where the initial spacing of thrust faults is small and displacement on individual thrusts is small such that, at the contact between horses, the roof thrust slopes towards the hinterland (Mitra 1986). True duplexes (such as those modelled by Boyer & Elliott (1982)) are formed by a particular combination of final thrust spacing, ramp angle and ramp height such that parts of all of the link thrusts and roof thrust are parallel to the frontal ramp of the duplex (Fig. 21b). Overlapping ramp anticlines are formed where the crests of successive ramp anticlines partially or totally overlap (Fig. 21c). A system of completely overlapping ramp anticlines in which the trailing branch lines are coincident is termed an antiformal stack (Fig. 21c).

Mitra (1986) further subdivided true duplexes depending upon their position with repect to larger thrusts (Fig. 21b). Duplexes may occur in the footwall to a ramp anticline, in the hangingwall to a ramp anticline and in front of a ramp anticline (Fig. 21b).

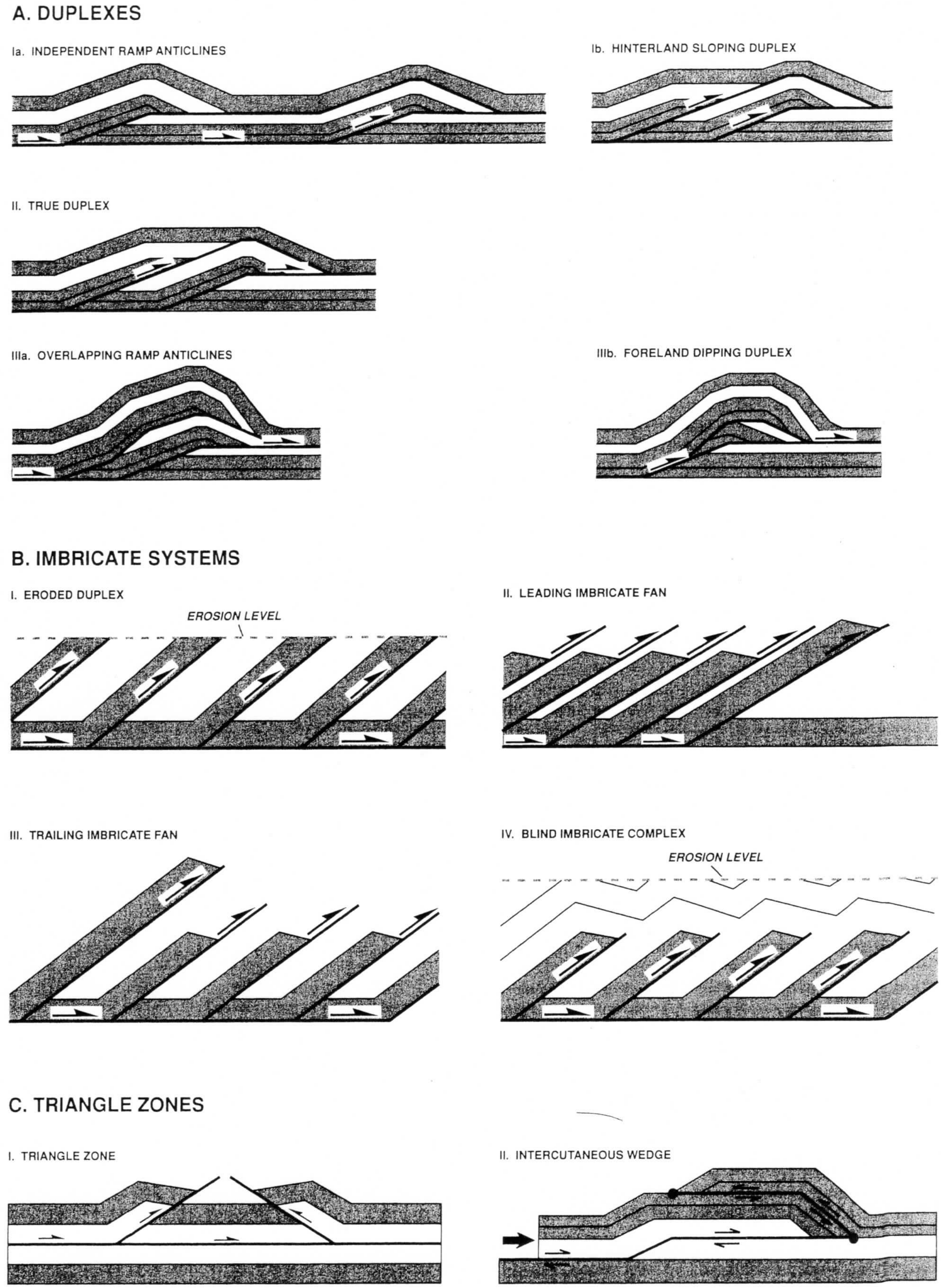

Figure 20. Thrust systems. (**a**) Duplexes. (**b**) Imbricate systems (schematic). (**c**) Triangle zones. (adapted after Boyer & Elliott 1982; Mitra 1986; and Woodward *et al.* 1989).

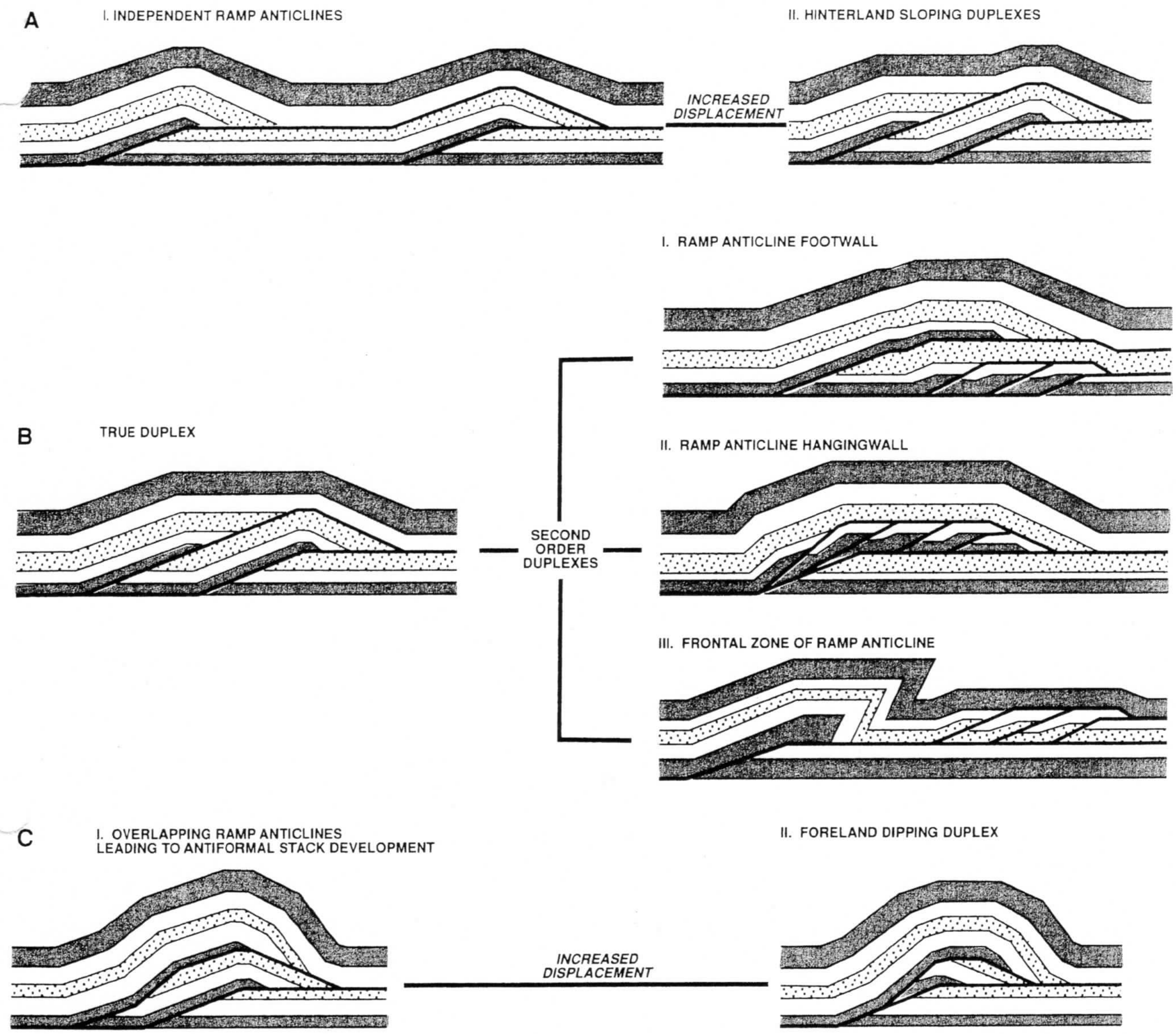

Figure 21. Duplex classification (modified after Mitra 1986). (**a**) Independent ramp anticlines and hinterland dipping duplexes. (**b**) True duplexes with second order duplexes. (**c**) Overlapping ramp anticlines which produce antiformal stacks and, with increased displacement, foreland dipping duplexes.

Antiformal stack: A duplex formed by overlapping ramp anticlines which have coincident trailing branch lines (Fig. 22). The individual horses are stacked up on top of each other such that they form an antiform.

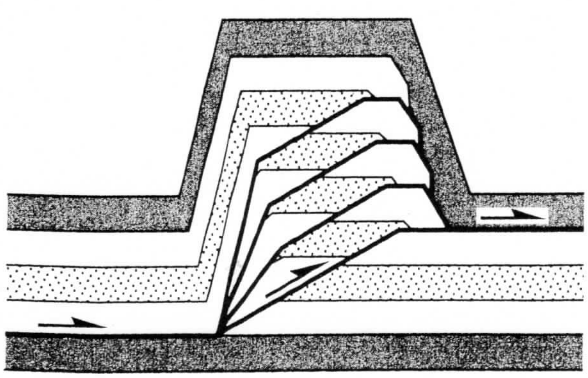

Figure 22. Antiformal stack.

Breached duplex: A duplex in which 'out of sequence movement' on the link thrusts have breached or cut through the roof thrust (Fig. 23). Butler (1987) discusses breaching of duplex structures.

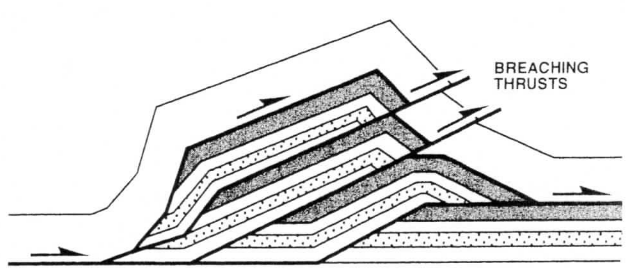

Figure 23. Duplex breached by reactivation of the link thrusts which displace the original duplex roof thrust.

Corrugated or bumpy roof duplex: A duplex in which the roof thrust is corrugated or folded (Fig. 24).

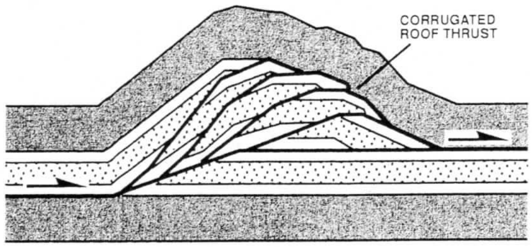

Figure 24. Corrugated or'bumpy roof' duplex.

Floor thrust: The lower thrust surface that bounds a duplex (Fig. 21).

Foreland dipping duplex; A duplex in which both the link thrusts and the bedding (or reference datum surfaces) dip towards the foreland of the thrust belt (Fig. 25).

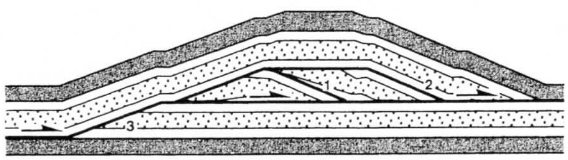

Figure 25. Foreland dipping duplex.

Hinterland dipping duplex: A duplex in which both the link thrusts and the bedding (or reference datum surfaces) dip towards the hinterland of the thrust belt (Fig. 26)

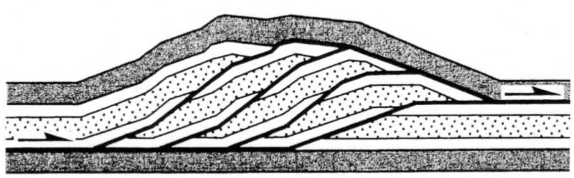

Figure 26. Hinterland dipping duplex.

Horse: A volume of rock completely surrounded (bounded) by thrust faults (Fig. 27).

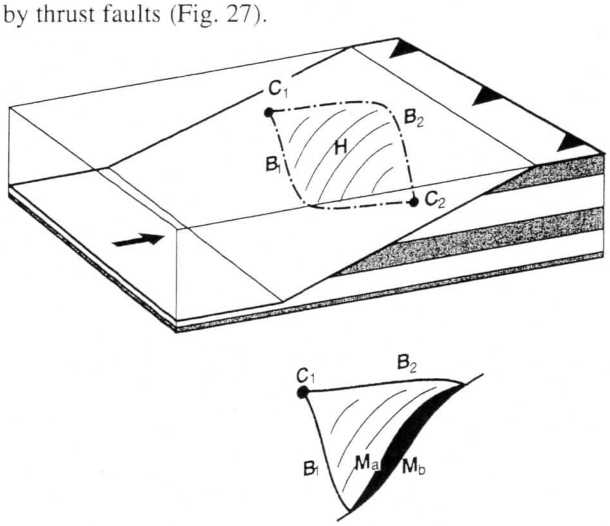

Figure 27. *Horse* **H** - a volume of rock enclosed by thrust faults. $\mathbf{B_1}$ and $\mathbf{B_2}$ are *branch lines*. C_1 and C_2 are *corner points* and $\mathbf{M_1}$ and $\mathbf{M_2}$ are thrust surfaces bounding the horse (adapted after Boyer & Elliott 1982).

Link thrusts: Imbricate thrusts that link the floor thrust to the roof thrust of the duplex (Fig. 28). Link thrusts are commonly sigmoidal in shape (McClay & Insley 1986).

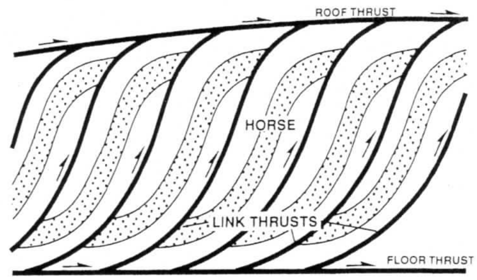

Figure 28. Duplex link thrusts (adapted after McClay & Insley 1986).

Passive roof duplex: A duplex in which the roof thrust is a *passive roof thrust* (Fig. 29) such that the roof sequence has not been displaced towards the foreland but has been underthrust by the duplex (Banks & Warburton 1986).

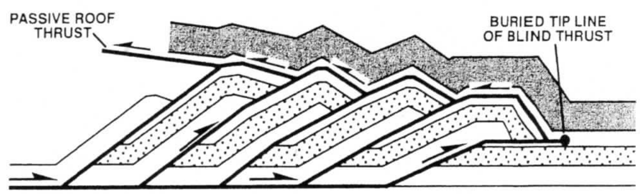

Figure 29. Passive roof duplex (adapted after Banks & Warburton 1986).

Passive roof thrust: A roof thrust in which the sequence above has not been displaced (e.g. it has remained attached to the foreland) but has been underthrust (Fig. 29). Passive roof thrusts are commonly developed where tectonic delamination or wedging occurs (see triangle zones below).

Planar roof duplex: A duplex in which the roof thrust is planar except where it is folded over the trailing ramp and over the leading ramp (Fig. 30). Groshong & Usdansky (1988) demonstrate that such a geometry is a result of a special combination of duplex thrust spacing and displacement.

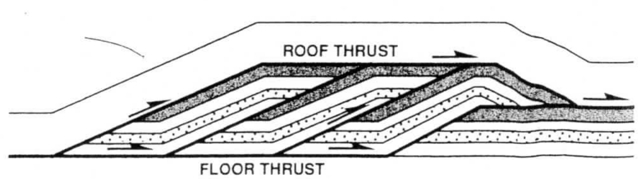

Figure 30. Planar roof duplex (true duplex model of Mitra 1986).

Roof thrust: The upper thrust surface that bounds a duplex (Fig. 30). Roof thrusts may be smooth or folded by movement on underlying thrusts of the duplex.

Smooth roof duplex: A duplex in which the roof thrust varies smoothly (Fig. 31) (see McClay & Insley 1986; Tanner 1991, this volume). Smoothly varying roof thrust geometry may be interpreted as indicating synchronous thrust movement (McClay & Insley 1986).

Figure 31. Smooth roof duplex where the roof thrust varies smoothly without folding by the underlying link thrusts (adapted after McClay & Insley 1986).

Truncated duplex: A duplex that is beheaded or truncated by an out of sequence thrust (Fig. 32).

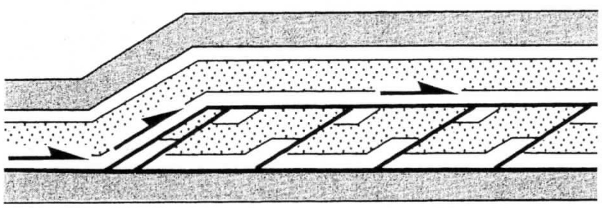

Figure 32. Truncated duplex in which the upper section (leading branch lines) has been removed by an 'out-of-sequence' thrust overriding the duplex.

Imbricate thrust systems

Imbricate thrust system: A closely related branching array of thrusts such that the thrust sheets overlap like roof tiles (Fig. 20).

Imbricate thrust systems may be formed a system of overlapping fault propagation folds (tip line folds - see *fault related folds and folding* below) as shown in Figure 33. Imbricate fans may also form from duplexes which have the leading branch lines eroded (Fig. 20). Boyer & Elliott (1982) point out the difficulty in distinguishing between imbricate systems formed from duplexes which have had the leading branch lines eroded and those imbricate systems formed from a branching array of thrusts that die out into tip lines and which have been subsequently eroded (Fig. 20).

Blind imbricate complex: An imbricate fan that remains buried such that the displacement on the imbricate faults below is compensated at a higher structural level by folding, cleavage development or another set of structures having a different style (Fig. 20) (see also Thompson 1981).

Imbricate fan: A system of linked, emergent thrusts that diverge upwards from a *sole thrust* (or floor thrust) (Fig. 33).

Leading imbricate fan: An imbricate fan that has most of its displacement on the leading (lowermost) thrust (Fig. 20).

Trailing imbricate fan: An imbricate fan that has most of its displacement on the trailing (highest) thrust (Fig. 20).

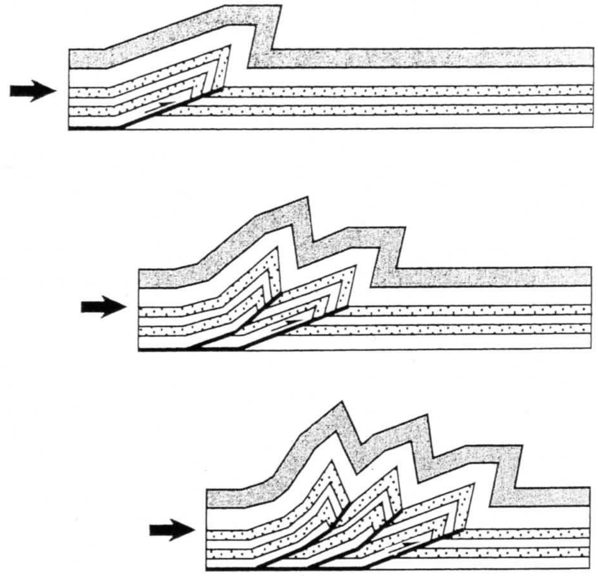

Figure 33. Imbricate fan formed from an array of overlapping fault-propagation folds (adapted after Mitra 1990).

Triangle zones

The term *'Triangle zone'* was first used to describe the thrustbelt termination in the southern Canadian Rocky Mountains (e.g. Price 1981). There it is a zone of opposed thrust dips, at the external margin of the thrust belt and often with a duplex or antiformal stack in the axial part. This is more correctly described as a *passive roof duplex* (Fig. 29). Such ' triangle zones' are basically intercutaneous wedges (Price 1986). A second usage of the term *triangle zone* refers to a combination of two thrusts with the same basal detachment and with opposing vergence such that they form a triangular zone (see below).

Intercutaneous thrust wedge: A thrust bounded wedge bounded by a sole or floor thrust at the base and by a passive roof thrust at the top (see Price 1986)

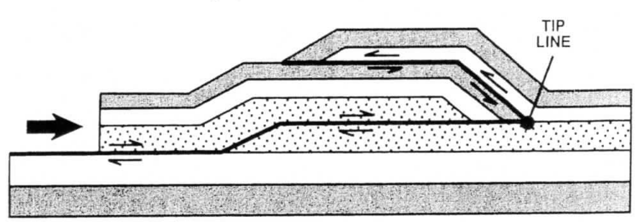

Figure 34. Intercutaneous thrust wedge (adapted after Price 1986).

Triangle zone: A combination of two thrusts with the same basal detachment and with opposing vergence such that they form a triangular zone (Fig. 35).

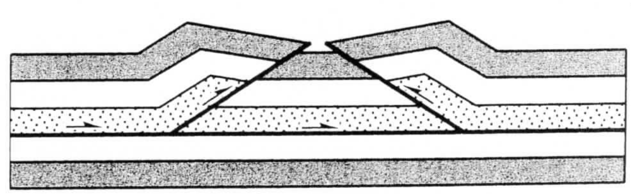

Figure 35. Triangle zone.

Thrust fault related folds and folding

This section of the glossary deals with thrust related folding and includes nappe structures generated by folding and thrusting. Detailed analysis of the geometries of thrust related folds have been given by various authors - fault bend folds (Suppe 1983; Jamison 1987), fault-propagation folds (Suppe 1985; Jamison 1987; Mitra 1990; Mosar & Suppe 1991, this volume) and detachment folds (Jamison 1987; Mitra & Namson 1989). Growth folds are analysed by Suppe *et al.* (1991, this volume).

Detachment fold: Detachment folds Jamison (1987) are folds developed above a detachment or thrust that is bedding parallel (i.e. the thrust is a flat and the folding does not require a ramp) (Fig. 36). Detachment folds require a ductile decollement layer (e.g. salt or shale) which can infill the space generated at the base of the fold (Fig. 36). Detachment folds are rootless and commonly disharmonic.

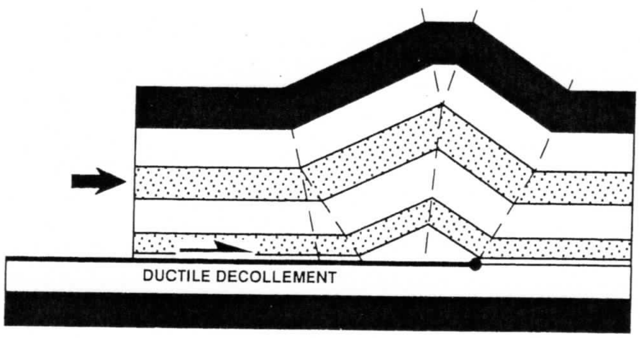

Figure 36. Detachment fold.

Fault-bend fold: A fold generated by movement of a thrust sheet over a ramp (Fig. 37) (analysed in detail by Suppe (1983).

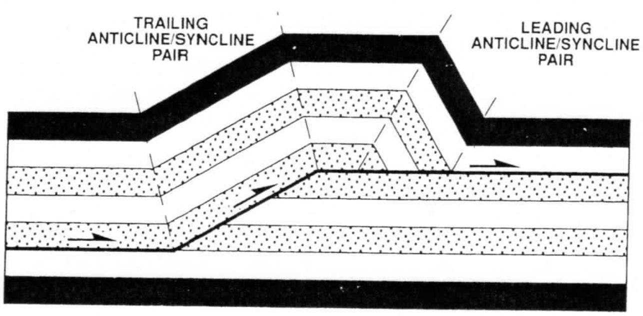

Figure 37. Fault-bend fold with leading and trailing anticline-syncline pairs.

Fault propagation fold: A fold generated by propagation of a thrust tip up a ramp into undeformed strata (Fig. 38). Also known as a *tip line fold*.

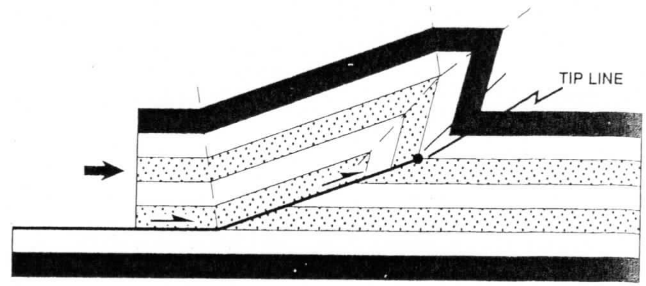

Figure 38. Fault-propagation fold.

Fold nappe: A nappe formed by a large recumbent overfold (Fig. 39) in which the underlimb is highly attenuated (cf. the Helvetic nappes, Ramsay 1981; Dietrich & Casey 1989)

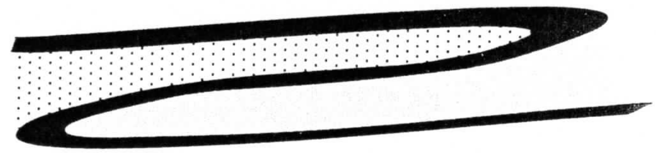

Figure 39. Fold nappe.

Footwall syncline: A syncline that is developed in the footwall to a thrust sheet below a ramp. Footwall synclines may develop by frictional drag below the thrust or develop from fault propagation folds.

Growth fold: A fold that develops in sedimentary strata at the same time as they are being deposited (Fig.40) (see Suppe *et al.* 1991, this volume). Growth folds (*growth anticlines*) may develop above the tip line of a thrust fault that is propagating upwards into the sedimentary section as it is being deposited. Strata typically thin onto the crest of the *growth anticline*.

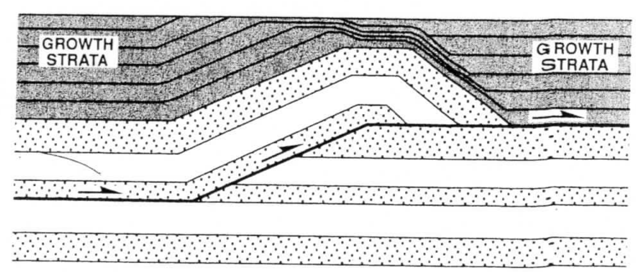

Figure 40. Growth fault-bend fold (after Zoetemeijer & Sassi 1991, this volume).

Growth strata: Strata that are deposited on a growth fold system as it develops (Fig. 40) and hence they record the evolution of the fold (see Suppe *et al.* 1991, this volume).

Lift-off fold: Lift-off folds (Mitra & Namson 1989) are detachment folds whereby the beds and the detachment are soclinally folded in the core of the anticline (Fig. 41). Lift-off folds require a ductile decollement layer such as salt or shale which can flow from the core of the fold.

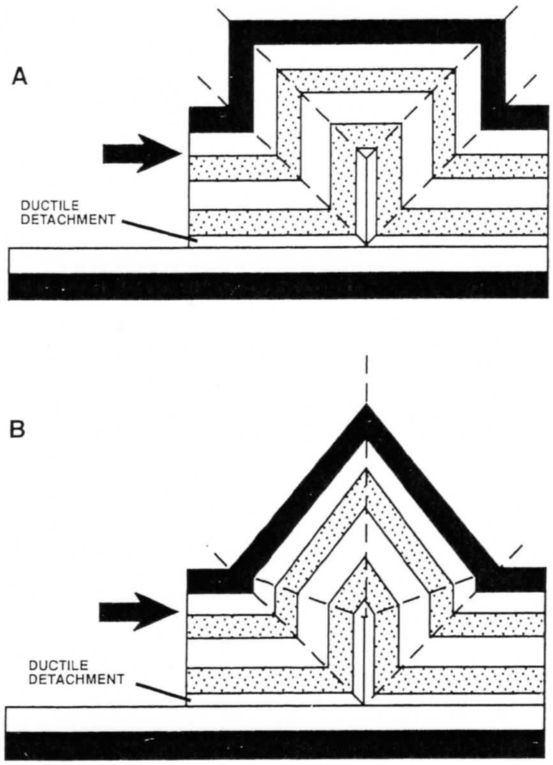

Figure 41. Lift-off folds in which the detachment is isoclinally folded in the core of the fold. A ductile detachment layer is needed in order to permit flow of ductile material from the collapsed fold core. **(a)** Box lift-off fold. **(b)** Chevron lift-off fold. (adapted after Mitra & Namson 1989)

Overthrust shear: A term used for thrust or fold nappes that have been subjected to bulk shear strain generally in the direction of nappe transport. See Ramsay *et al.* (1983), Dietrich & Casey (1989), and Rowan & Kligfield (1991, this volume) for discussions of overthrust shear and nappe emplacement.

Ramp anticline: An anticline in the hangingwall of a thrust generated by movement of the thrust sheet up and over a ramp in the footwall (Fig. 30).

Ramp syncline: A syncline in the hangingwall of a thrust generated by movement of the thrust sheet up and over a ramp in the footwall (Fig. 37). Ramp anticlines and ramp synclines occur in geometrically and kinematically linked pairs - a *leading anticline-syncline pair* and a *trailing anticline-syncline pair* (Fig. 37).

Thrust nappe: A large thrust sheet commonly with significant displacement (e.g. the Moine nappe). A thrust nappe may be generated from a recumbent fold in which the lower limb has been faulted out to form the sole thrust of the nappe (Fig. 18).

Transported fault-propagation fold: A fault propagation fold that has been transported by thrust that has broken through onto an upper flat (Fig. 42).

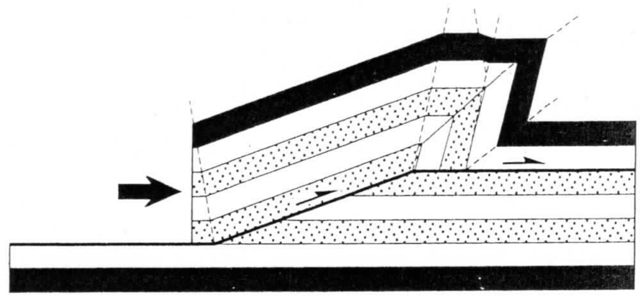

Figure 42. Transported fault propagation fold.

Translated (or transported) detachment fold: A detachment fold that is transported by a thoroughgoing thrust such that it is displaced from its point of formation (e.g. up a footwall ramp) (Fig. 43). Mitra (1990) discusses the differences between translated (transported) fault-propagation folds and translated (transported) detachment folds.

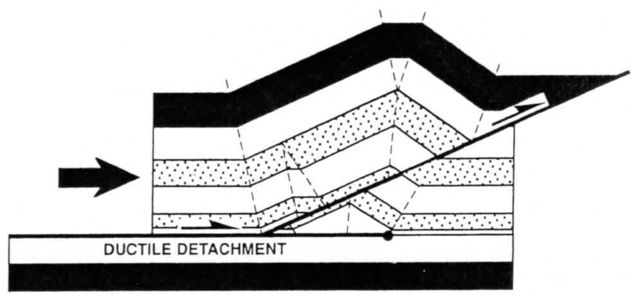

Figure 43. Transported detachment fold (adapted after Mitra 1990).

Thrust structures in 3D

The movement of a thrust sheet over a corrugated surface will generate flat topped anticlines and domes. These are termed culminations (Dahlstrom 1970; Butler 1982) and the limbs of these structures are termed culmination walls.

Culmination: An anticline or dome with four way closure generated by movement of the thrust sheet over underlying ramps.

Displacement transfer zone: The zone where displacement is transferred from one thrust to another (Dahlstrom 1970). Displacement transfer zones may occur by simple *en-echelon overlap* of thrust faults (Fig. 44) or by *tear faults* parallel to the direction of tectonic transport (see *tear faults* - below).

Dorsal culmination wall: The limb which is developed over the rear ramp of the culmination and dips in a direction opposite (i.e. 180°) to the tectonic transport direction (Fig. 45).

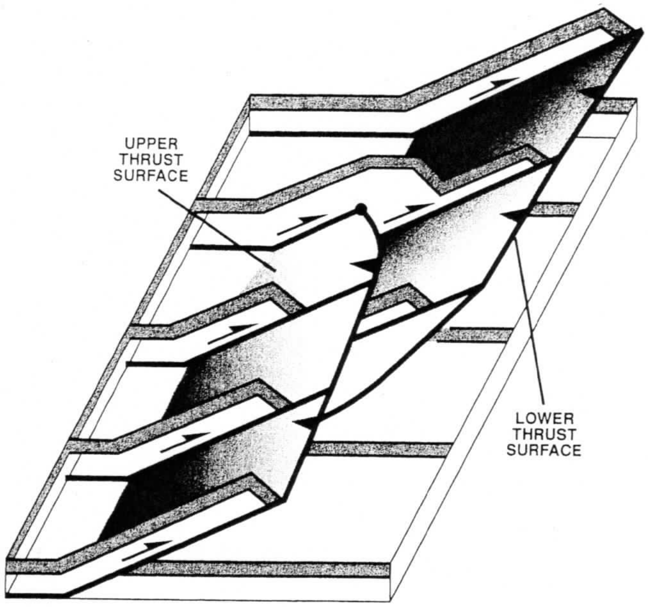

Figure 44. Displacement transfer by *en echelon* overlap of thrust faults.

Frontal culmination wall: A culmination limb which is developed over a frontal ramp and dips in the direction of tectonic transport (Fig. 45).

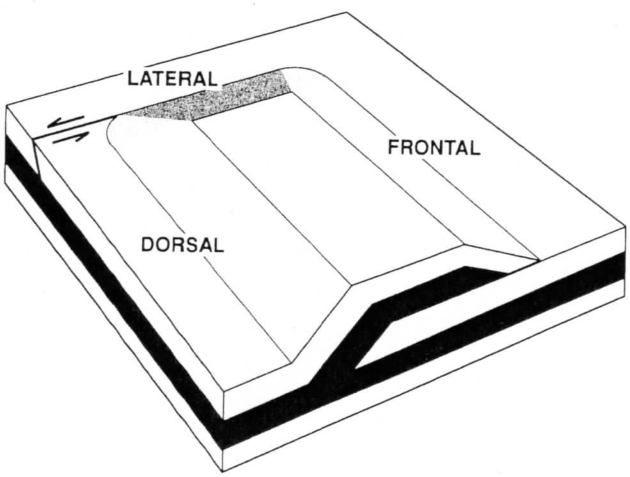

Figure 45. Culmination walls.

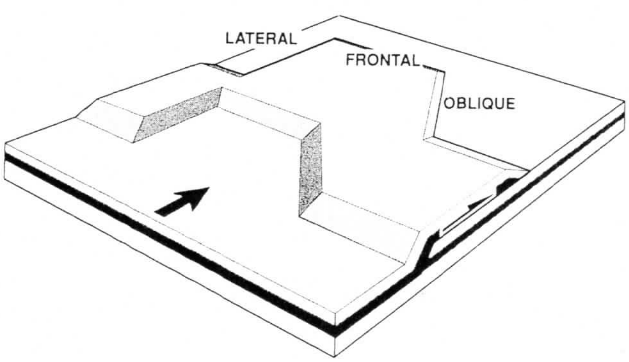

Figure 46. Ramp related folds in the hangingwall of a thrust system.

Frontal ramp fold: A fold formed by translation of the thrust sheet over a frontal ramp (Fig. 46).

Lateral culmination wall: A culmination limb which is developed over a lateral ramp and dips in a direction 90° to the tectonic transport direction (Fig. 45).

Lateral ramp fold: A fold formed by translation of the thrust sheet over a lateral ramp (Fig. 46).

Oblique culmination wall: A culmination limb which is developed over an oblique ramp and dips in a direction oblique to the tectonic transport direction.

Oblique ramp fold: A fold formed by translation of the thrust sheet over an oblique ramp (Fig. 46).

Tear fault. A strike-slip fault parallel to the thrust transport direction and separating two parts of the thrust sheet each of which have different displacements (Fig. 47).

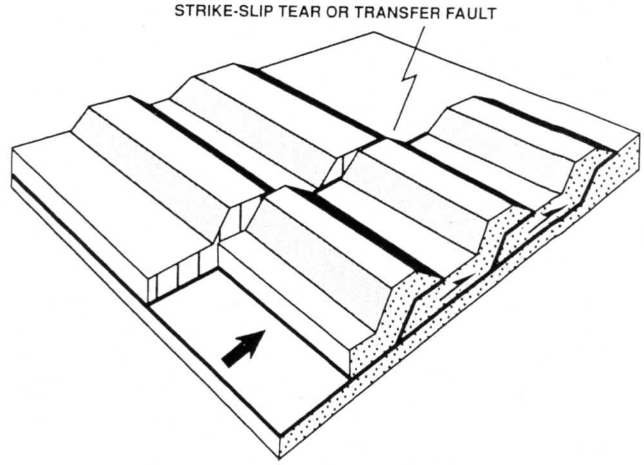

Figure 47. Tear fault parallel to the thrust transport direction and separating two parts of the thrust sheet each of which have different displacements.

Window: A hole within a thrust sheet whereby the hangingwall section of a thrust sheet has been removed by erosion thus exposing the underlying structures. Windows commonly form through erosion of culminations such that the underlying thrust system (commonly imbricates or duplexes) is revealed. Boyer & Elliott (1982) illustrate different types of windows formed by erosion of various duplex forms.

Thrust sequences

Thrust sequence: The sequence in which new thrust faults develop.

The sequence of development of thrust faults within a thrust belt or thrust system is an important parameter needed for the interpretation of both the geometry and the kinematic evolution of a thrust belt. It is essential for the construction of balanced and restored sections (Boyer and Elliott 1982; Boyer 1991, this volume; Butler 1987; Morley 1988; Suppe 985; Woodward *et al.* 1989). A long accepted paradigm for thrust tectonics is that, in foreland fold and thrust belts, thrust faults develop sequentially in a sequence that both nucleates in a forward-breaking sequence and verges towards the foreland (Dahlstrom 1970; Bally *et al.* 1966; Boyer & Elliott 1982; Butler 1982). Recently these basic 'rules' of thrust tectonics have been challenged (see Boyer 1991, this volume; and Tanner 1991, this volume).

Breaching: Breaching occurs where an early formed thrust is cut by later thrusts (Butler 1987) (Fig. 48). It is a term describing the local geometric relationships between thrusts. The term may be applied to a *breached duplex* where the link thrusts do not join or anastomose with the roof thrust but cut and displace it (Fig. 23).

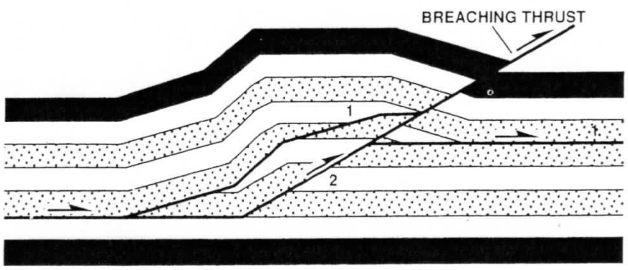

Figure 48. Breached thrust - an early formed thrust cut by later thrust. Numbers indicate sequence of faulting.

Break-back sequence: The sequence of thrusting where new (younger) thrusts nucleate in the hangingwalls of older thrusts and verge in the same direction as the older thrusts (Fig. 49).

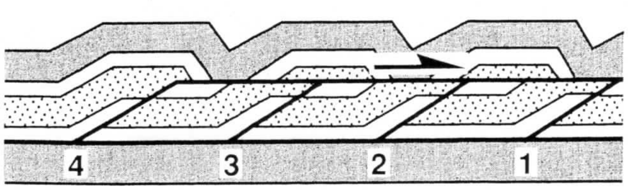

Figure 49. Break-back thrust sequence. Numbers indicate sequence of faulting.

Forward-breaking sequence: The sequence of thrusting in which new (younger) thrust faults nucleate in the footwalls of older thrusts and verge in the same direction as the older thrusts (Fig. 50).

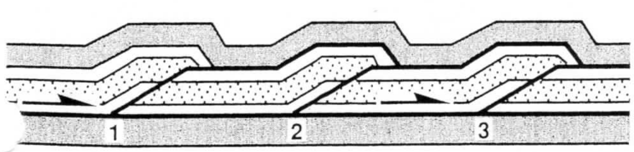

Figure 50. Forward-breaking or "piggy-back thrust" sequence. Numbers indicate sequence of faulting.

In sequence thrusting: A thrust sequence that has formed progressively and in order in one direction (i.e either a forward-breaking sequence or a break-back sequence). Figures 49 & 50 show in-sequence thrusting.

Out-of-sequence thrusting The opposite to 'in-sequence thrusting'. Thrust faulting which develops in a sequence other than in sequence (Fig. 51). Break-back sequences of thrusts have commonly been called out-of sequence thrusts but the term should be more appropriately used to describe thrust sequences which do not conform to a either a progressive forward-breaking or break-back sequence (Fig. 51). Out of sequence thrusts commonly cut through and displace pre-existing thrusts. Morley (1988) and Butler (1987) discuss out of sequence thrusting.

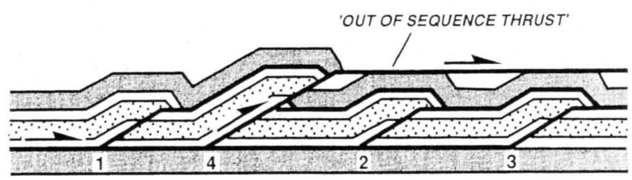

Figure 51. "Out-of-sequence" thrust cutting into a foreland-vergent thrust system. Numbers indicate sequence of faulting.

Piggy-back thrust sequence: Piggy-back thrust sequence occurs when topographically higher but older thrusts are carried by lower younger thrusts (Fig. 50). This is essentially the same as a *forward-breaking* thrust sequence.

Synchronous thrusting: Synchronous thrusting occurs when two or more thrusts move together (i.e. not in a piggy-back sequence). Boyer (1991, this volume) postulates that synchronous thrust movement may be significant in the Rocky Mountains of western North America.

Models for thrust faulting

The critical Coulomb wedge model

Wedge type models for the development of fold and thrust belts were first analysed by Elliott (1976) and Chapple (1978). The critical taper model or the critical Coulomb wedge model incorporating brittle frictional rheology for the emplacement of accretionary wedges and foreland fold and thrust belts was postulated by Davis et al. (1983) and subsequently developed by Dahlen and others (see review by Dahlen 1990). The critical wedge model assumes that the accretionary wedge or foreland fold and thrust belt has a triangular cross-section, a characteristic surface slope α and a basal decollement dip of β (Fig. 52). The wedge is composed of material that has a Navier-Coulomb rheology. The wedge forms by pushing an initial layered sequence from behind such that thrusts propagate in sequence (towards the foreland) until a critical taper ($\alpha + \beta$) is attained at such time that subsequent deformation involves transport of the whole wedge along the basal decollement or the wedge continues to grow in a self-similar fashion by addition of new material at the wedge toe but maintaining the critical taper. Critical wedge models have used to explain the development of accretionary prisms and foreland fold and thrust belts (e.g. Dahlen & Suppe 1988; Dahlen 1990; Willett 1991, this volume; Liu *et al.* 1991, this volume) but have been criticised by Woodward (1987).

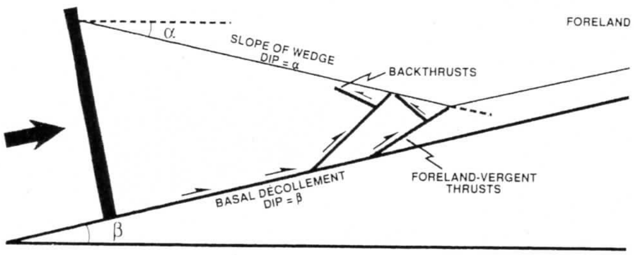

Figure 52. Idealised Coulomb wedge model for the development of an accretionary wedge or foreland fold and thrust belt (cf. Davis et al. 1983; Dahlen 1990).

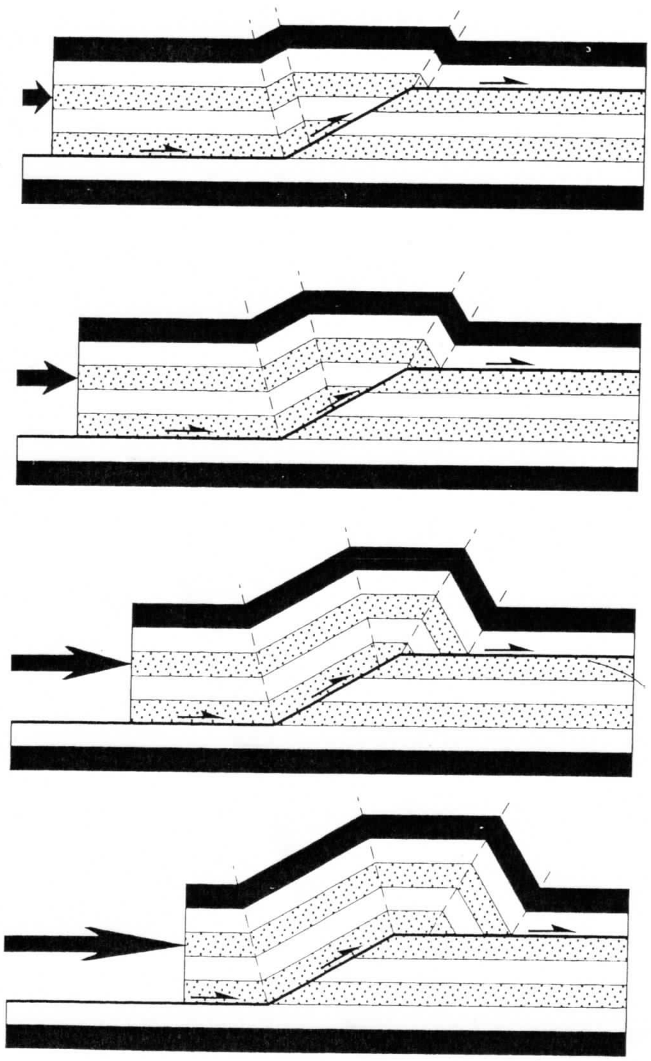

Figure 53. Self-similar growth model for the development of a fault-bend fold.

Self-similar thrust models

Self-similar model: It is commonly assumed that spatial variations in thrust system geometries reflect temporal variations in the evolution of the structure (Fischer & Woodward 1991, this volume). This is the basis for the self-similar growth model for thrust structures such as fault-bend folds or fault-propagation folds where, through time, the structure grows in amplitude as a simple geometric progression of the first formed structural feature (Fig. 53). This model assumes that the structure does not change form with time (e.g. evolve from a detachment fold to a fault propagation fold) - an assumption challenged by Fischer & Woodward (1991, this volume).

Inversion

Inversion tectonics: Inversion tectonics is a switch in tectonic mode from extension to compression such that extensional basins are contracted and become regions of positive structural relief. Inversion tectonics is generally accepted to involve the reactivation of pre-existing extensional faults such that they undergo reverse slip and may eventually become thrust faults (Fig. 54). The modern concepts of inversion tectonics are discussed in Cooper & Williams (1989). Thrust structures in inverted basins include footwall shortcut thrusts and 'out-of-the-graben' thrusts (Fig. 13).

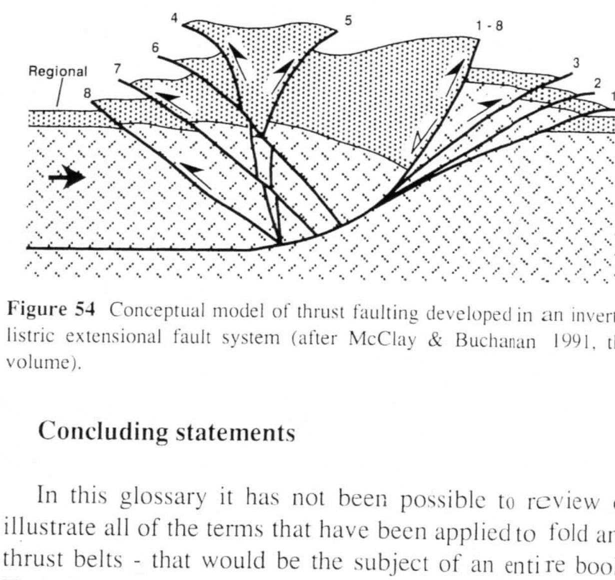

Figure 54 Conceptual model of thrust faulting developed in an inverted listric extensional fault system (after McClay & Buchanan 1991, this volume).

Concluding statements

In this glossary it has not been possible to review or illustrate all of the terms that have been applied to fold and thrust belts - that would be the subject of an entire book. Techniques of analysis such as the construction and restoration of balanced sections have been recently reviewed by Geiser (1988), Mitra & Namson (1989) and Woodward *et al.* (1989) and are not dealt with here. The definitions and interpretations of the terms presented in this glossary are the responsibility of the author and no doubt some will be debated as to exact interpretation and usage.

This glossary was compiled with the help of Tim Dooley and Joaquina Alvarez-Marron who are thanked for assistance with the illustrations. I. Davison, J. Alvarez-Marron, R. Knipe and C. Banks are thanked for critical reviews and comments.

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