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Strike-slip duplexes

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Abstract—Strike-slip fault systems often contain zones of steep imbricate faults geometrically similar to imbricate fans and duplexes in dip-slip, thrust and normal, fault systems. They are evident in map view rather than in vertical sections. Examples of duplexes are cited from both active and ancient systems and from theoretical and physical models. Duplexes may form at bends on strike-slip faults by a process kinematically analogous to the sequential imbrication of ramps on dip-slip faults. However some may form, and many may initiate, as non-sequential 'Riedel' fractures at fault offsets or on straight fault segments. This process is more marked than in dip-slip systems where primary anisotropy such as bedding exerts more control on fault geometry.

Strike-slip duplexes may be shunted along the fault system parallel to the regional slip vector. However, duplexes or individual horses will usually also move up or down perpendicular to the slip vector because of the unconstrained upper surface to the fault system. These factors mean that no section through a strike-slip system should be expected to area balance. The faults of strike-slip duplexes and imbricate fans may root in kinematically necessary low-dip faults or may converge downwards and appear in vertical sections as flower structures.

DUPLEX AND FAN GEOMETRY

IMBRICATE fault arrays have long been recognized in thrust systems (review by Boyer & Elliott 1982). Imbricate faults that splay upwards off a sole thrust form an *imbricate fan*, and those that converge upwards again into a roof thrust form a *duplex* (Dahlstrom 1970). Formation of duplexes and fans by sequential contractional collapse of a footwall ramp is understood in theory and demonstated by natural examples (e.g. Boyer & Elliott 1982, Butler 1982). Extensional duplexes have now been recognized at ramps on major normal faults (Gibbs 1984). A number of previous authors (e.g. Kingma 1958, Lensen 1958) have recognized imbricate fault arrays in strike-slip systems, best seen in map view rather than vertical section. In this paper we explore the analogy between these strike-slip fans and duplexes and their better known dip-slip counterparts. The formation of strike-slip duplexes is best understood as a kinematic response to imposed boundary constraints, rather than by the stress-control or bulk strain approaches usually applied to wrench tectonics.

An idealized strike-slip system (Fig. 1) shows the terminology used in this paper. In map view faults comprise *straights*, segments sub-parallel to the regional slip vector, and *bends* oblique to it. Displacements may be transferred between two faults across an *offset*. Pure strike-slip on the straights necessarily causes potential overlap at a bend of one sense (*restraining bend*, Crowell 1974) and a potential void at a bend of the other sense (*releasing bend*, Crowell 1974). *Contractional duplexes* may form at restraining bends or offsets and *extensional duplexes* at releasing bends or offsets. At the lateral fault tips, splays of smaller faults may form steep *imbricate fans* which themselves may be extensional or contractional. Fans may be designated as *leading* or *trailing* depending on the sense in which the major, higher displacement, strand flanks the fan (cf. Boyer & Elliott 1982). Imbricate faults usually have a dip-slip component (Fig. 1), dominantly with a normal sense in an extensional fan or duplex and a reverse sense in a contractional fan or duplex.

EXAMPLES OF STRIKE-SLIP DUPLEXES

Natural examples of strike-slip duplexes (Fig. 2) will be referred to individually later. However, some general features are of note here. The duplexes are usually bounded by two continuous major fault zones, possibly with large displacement (e.g. Figs. 2d(1), i, k & l), or two zones of high fracture density (Figs. 2h(3) & j). Between these zones smaller en-échelon faults define the duplex structure. These faults usually have a component of strike-slip combined with either normal dip-slip (Figs. 2i & j) or reverse dip-slip (Fig. 2g). The individual horses defined by these imbricate faults have lengths varying between about half and twice the spacing of the major faults that bound the duplex. This ratio is probably modified by deformation and rotation of the horse.

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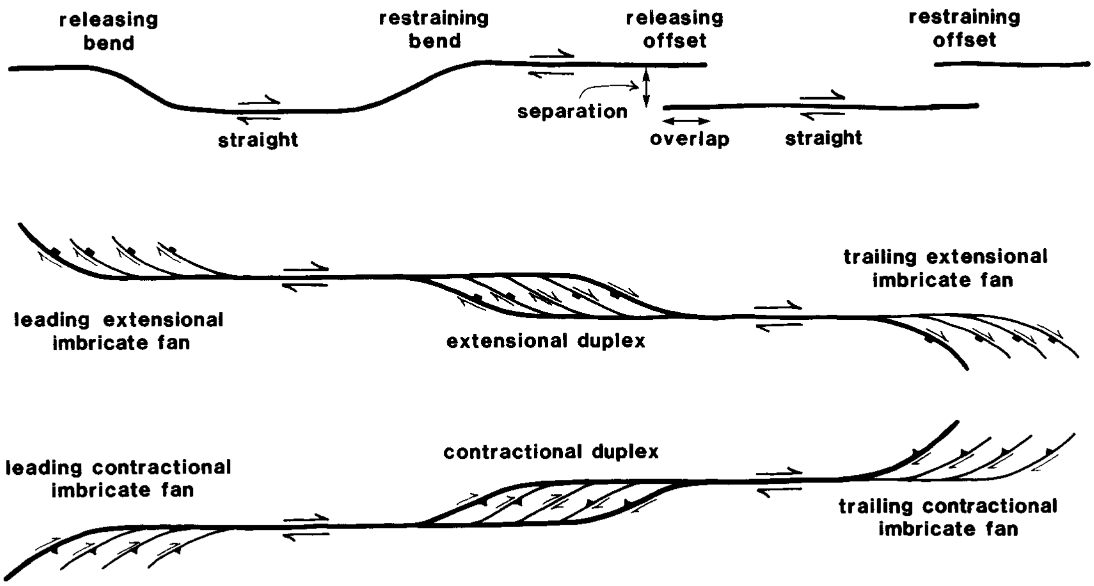

Fig. 1. Map view of an idealized dextral strike-slip system to illustrate terminology.

Some duplexes develop at major bends on the main fault (Fig. 2h(3)) or at major offsets (Fig. 2c,a(1)). Others develop at more subtle offsets (Figs. 2f & g) and some on essentially straight fault segments (Fig. 2b(1)).

COMPARISON OF DUPLEXES IN STRIKE-SLIP AND DIP-SLIP SYSTEMS

Despite some geometric similarities strike-slip duplexes need not behave kinematically like dip-slip duplexes. Important differences arise from the different attitude of strike-slip fault planes and the slip vector with respect to the vertical and thus to the free topographic surface. The thickening of a contractional duplex or thinning of an extensional duplex in a dip-slip, reverse or normal, fault system can be efficiently accommodated by distortion of the free ground surface (Fig. 3a & b). This allows plane strain to be maintained in a vertical plane through the displacement vector. The widening or narrowing of a strike-slip duplex must be accommodated by lateral distortion of surrounding rock in order to maintain plane strain in a horizontal section (Fig. 3c). This may be geometrically possible by compensation on a laterally adjacent fault strand. However usually some vertical accommodation takes place (Fig. 3d) by uplift around a contractional duplex or subsidence around an extensional duplex. Plane strain is not maintained. In a limiting non-plane strain case (Fig. 3e) the area around the duplex remains unstrained, and volume balance is maintained by localized uplift or subsidence of the duplex itself. The duplex faults will have strong dip-slip components, normal at a releasing bend and reverse at a restraining bend.

There are further differences. Vertical strike-slip faults lack the gravitational potential normal to the fault plane which may be an important factor in establishing fault propagation sequences in dip-slip duplexes (Boyer & Elliott 1982). The distinction between footwall and hangingwall structures is inappropriate. Duplexes in dip-slip systems usually retain a similar character along one major fault zone, whereas extensional and contractional duplexes may coexist along the length of a single strike-slip zone (e.g. Fig. 3c). Finally, strike-slip faults usually cut material anisotropies such as bedding at high angles. Weak stratigraphic horizons are badly oriented for localizing strike-slip faults, and thus isotropic rheological theory is more relevant in strike-slip systems. This lack of bedding control will in part account for the braided, disorganized geometry of mature strike-slip zones.

PLANE STRAIN DUPLEXING

This section details possible processes for forming strike-slip duplexes in approximate plane strain in a horizontal surface. Plane strain is probably rarely maintained in real systems, but the assumption serves to introduce the kinematic models. The additional complications of non-plane strain deformation will be detailed in a later section. Duplex geometries probably develop in strike-slip zones by several different kinematic processes. This contrasts with duplexing in thrust belts, currently thought to result mainly from one process, progressive forward collapse of footwall ramps (Boyer & Elliott 1982).

Duplexing at bends

This process (Fig. 4) is analogous to duplex formation at ramps in dip-slip systems. Successive imbricate slices (horses) are cut from the major fault walls at the bend by progressive propagation of new imbricate faults outward from the initial fault strand. Inward propagation within the first horse or pair of horses is theoretically possible but unless the horses are long there is little scope for progressive imbrication and therefore a low potential for

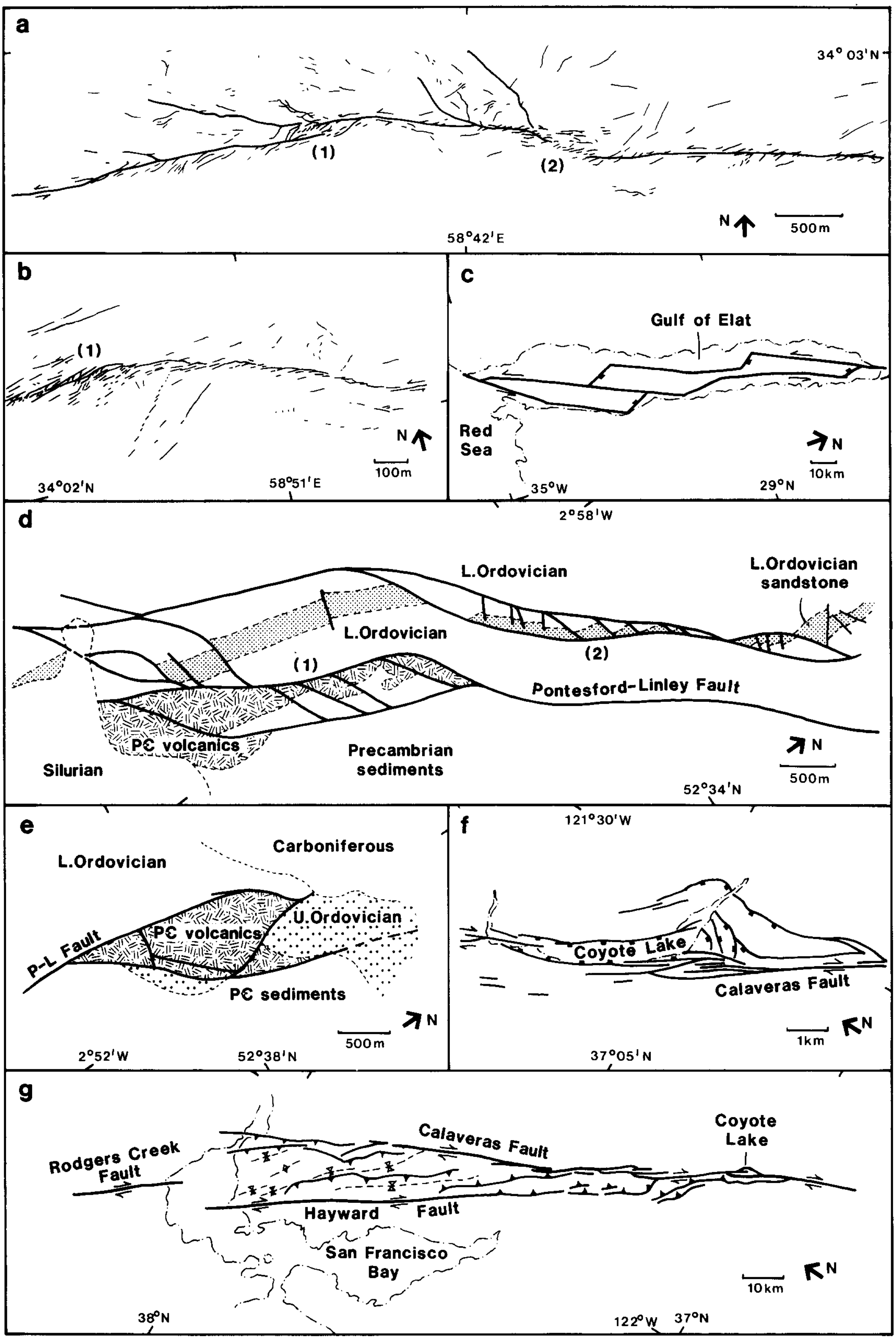

Fig. 2. Natural examples of strike-slip duplexes: (a & b) Dasht-e-Bayaz fault, Nimbluk Valley, Iran (Tchalenko & Ambraseys 1970); (c) Gulf of Elat (Ben Avraham *et al.* 1979); (d & e) Pontesford–Linley fault zone, Wales (Dean & Dineley 1961, Whittard 1979); (f) Calaveras fault, Coyote Lake, California (Aydin & Page 1984); (g) East Bay Hills, California (Aydin & Page 1984). *Continued.*

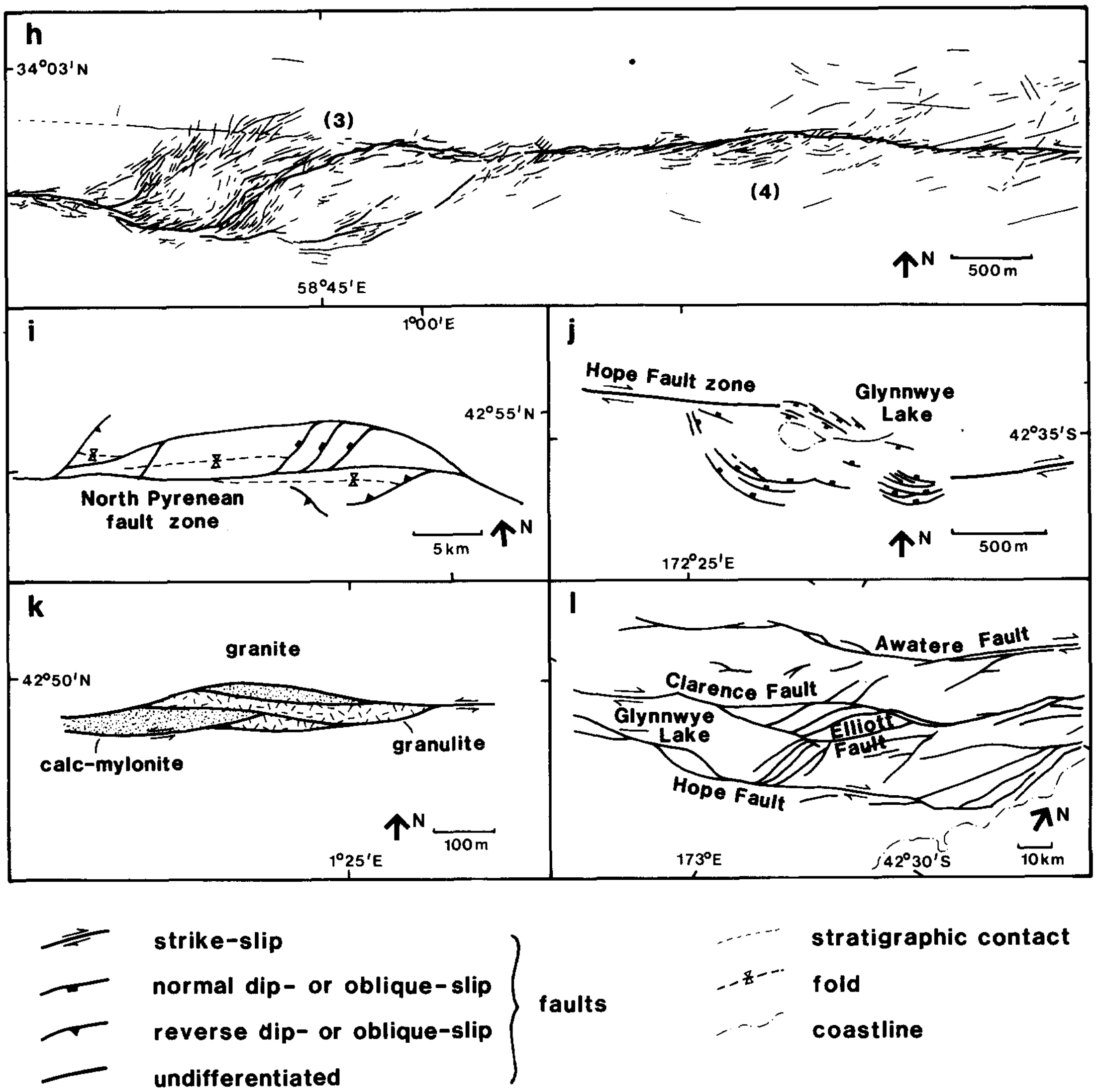

Fig. 2 *continued* (h) Dasht-e-Bayaz fault, Nimbluk Valley, Iran (Tchalenko & Ambraseys 1970); (i & k) North Pyrenean fault zone (Fischer 1984); (j) Glynnwye Lake, New Zealand (Freund 1971) and (l) Marlborough fault system, New Zealand (Freund 1974).

adjusting to displacement on the major faults. Fault propagation may be symmetric about the initial bend or asymmetric with imbricates being cut preferentially from one wall (Fig. 4). The geometry of an asymmetric system depends on whether each new horse is cut from a fault wall which is unstrained (Figs. 4c & e) or from a wall which has strained as it has negotiated the fault bend (Figs. 4b & f). In a symmetric system, outward propagating faults must always cut strained wall rocks (Figs. 4a & d). Whilst symmetric propagation may be possible during early development of duplexes, asymmetric propagation will be favoured by developing contrasts in lithology, structural anisotropy and stress distribution induced by the displacement itself.

To maintain plane strain and zero bulk volume change the shortening of a contractional duplex must be balanced by increase in its width, and lengthening of an extensional duplex by a width decrease. This bulging and necking of duplexes causes bending of the bounding fault strands and requires geometric accommodation in surrounding rocks (Figs. 3 and 4). This accommodation is geometrically analogous to hangingwall culminations and depressions above duplexes in dip-slip systems. However, in a plane strain strike-slip system the excess volume at bulges must be balanced by the volume deficit at thinning duplexes. This balance could theoretically occur along one major fault zone, but is more likely to occur between two adjacent zones in a strike-slip system. These strain compatibility problems contribute to the complexity of major strike-slip systems.

Duplexing at bends has not been modelled theoretically or physically, though models of fault offsets described below are relevant and confirm the orientation of imbricate faults if not their developmental sequence. A natural example occurs on the active Dasht-e-Bayaz fault, Iran (at location 3, Fig. 2h). This incipient extensional duplex has a throughgoing central strand flanked symmetrically by two imbricate fault zones defining horses with internally lower fracture density. From the fracture connectivity the central fault zone probably initiated earlier than the flanking zones. The length of each horse (parallel to the major strike-slip fault strands) is about one and a half times the separation of the major strands at the bend. A possible asymmetric example

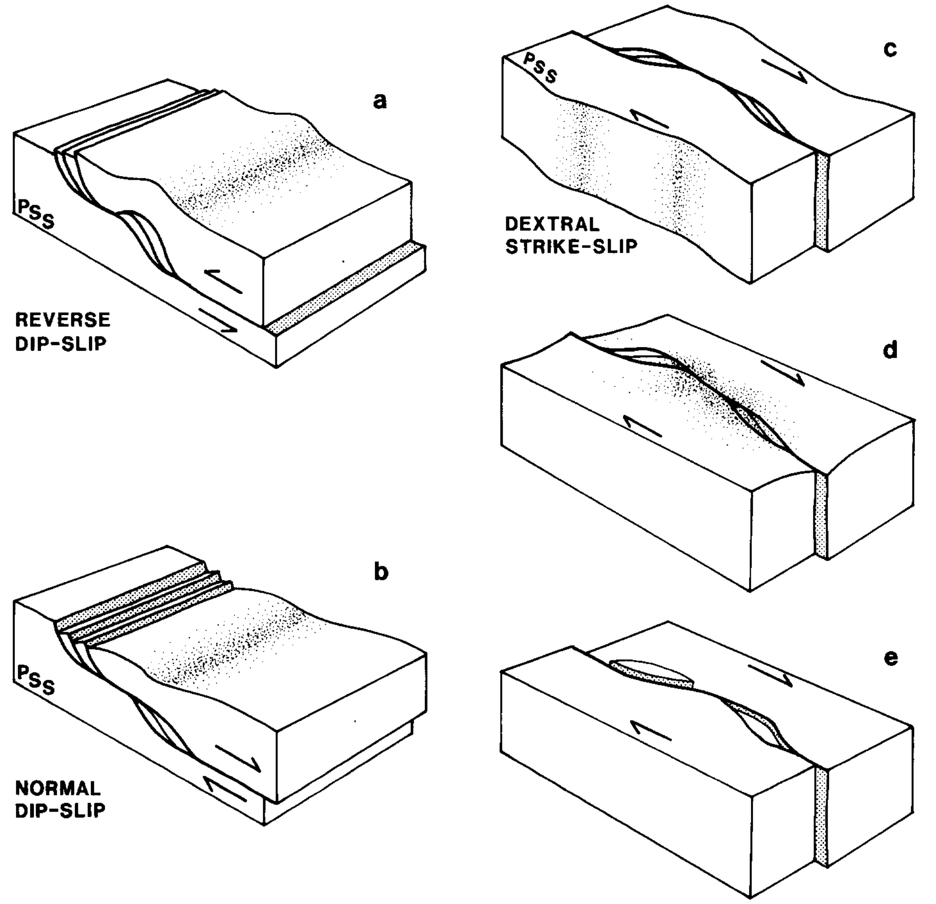

Fig. 3. Geometric accommodation of duplexes in dip-slip systems (a & b) by ground surface distortion compared with the need for lateral distortion to maintain plane strain in a strike-slip system (c). PSS indicates plane-strain section. Accommodation of strike-slip duplexes usually involves uplift or subsidence around the duplex (d) or, in the extreme, localized differential uplift or subsidence of the duplex itself (e).

with a horse being cut from the southern wall occurs at a gentle restraining bend on the same fault (location 4, Fig. 2h). An example of a contractional duplex occurs at a restraining bend between the Clarence and Elliott faults, New Zealand (Fig. 2l). A possible ancient example (location 1, Fig. 2d) occurs on the Palaeozoic Pontesford–Linley fault, Wales. This appears to be an extensional duplex compatible with a releasing bend in a dextral system.

Duplexing at offsets

Offset fault traces may reflect two separate faults or two en-échelon strands that curve helicoidally into a single fault at depth (Naylor *et al.* in press). Duplexing at offsets (Fig. 5) involves first the isolation of a horse by two imbricate strike-slip faults that propagate off the lateral tips of the main faults. The kinematic history will depend on the amount of overlap between the two main fault strands. For small overlap (Fig. 5a) the system can behave as a fault bend as soon as at least one of the new faults has linked with the other main fault and is taking most of the displacement. New horses can form by either symmetric or asymmetric outward progression of new imbricate faults as at bends (Fig. 4). For large overlap, inward progression of fault development is possible (Fig. 5b) but is only effective where displacement is low relative to the overlap.

Fault patterns at offsets have previously been modelled using elastic theory. The results of Segall & Pollard (1980) show that shear fractures will tend to propagate from the lateral tips of the major faults (Figs. 6a & b) with synthetic strike-slip faults deflecting progressively towards the opposite major fault strand. Rodgers' (1980) results also show this concave inward fault pattern (Figs. 6c & d) which matches closely the early stage of duplex formation at offsets (Fig. 5). Although some of the offsets in the theoretical models had substantial overlap, the results cannot be used to predict likely fault propagation sequences. They show only 'potential' fault directions in isotropic rock. Real systems will be strongly influenced by the anisotropy introduced by the new fractures themselves.

The theoretical results for low displacement are corroborated by clay-cake models of fault patterns above underlying offset faults (Hempton & Neher 1986). At all stages of the experiments, two zones of high fracture density join the lateral tip of each underlying fault to the trace of the opposing fault (Fig. 6e). These two shear zones define an intervening less deformed horse.

Natural examples of duplexes apparently formed at offsets occur on the Dasht-e-Bayaz fault (locations 1, 2, Fig. 2a), on the Hope fault zone, New Zealand (Fig. 2j) and on the Calaveras fault, California (Fig. 2f). However, the last two probably depart significantly from plane strain.

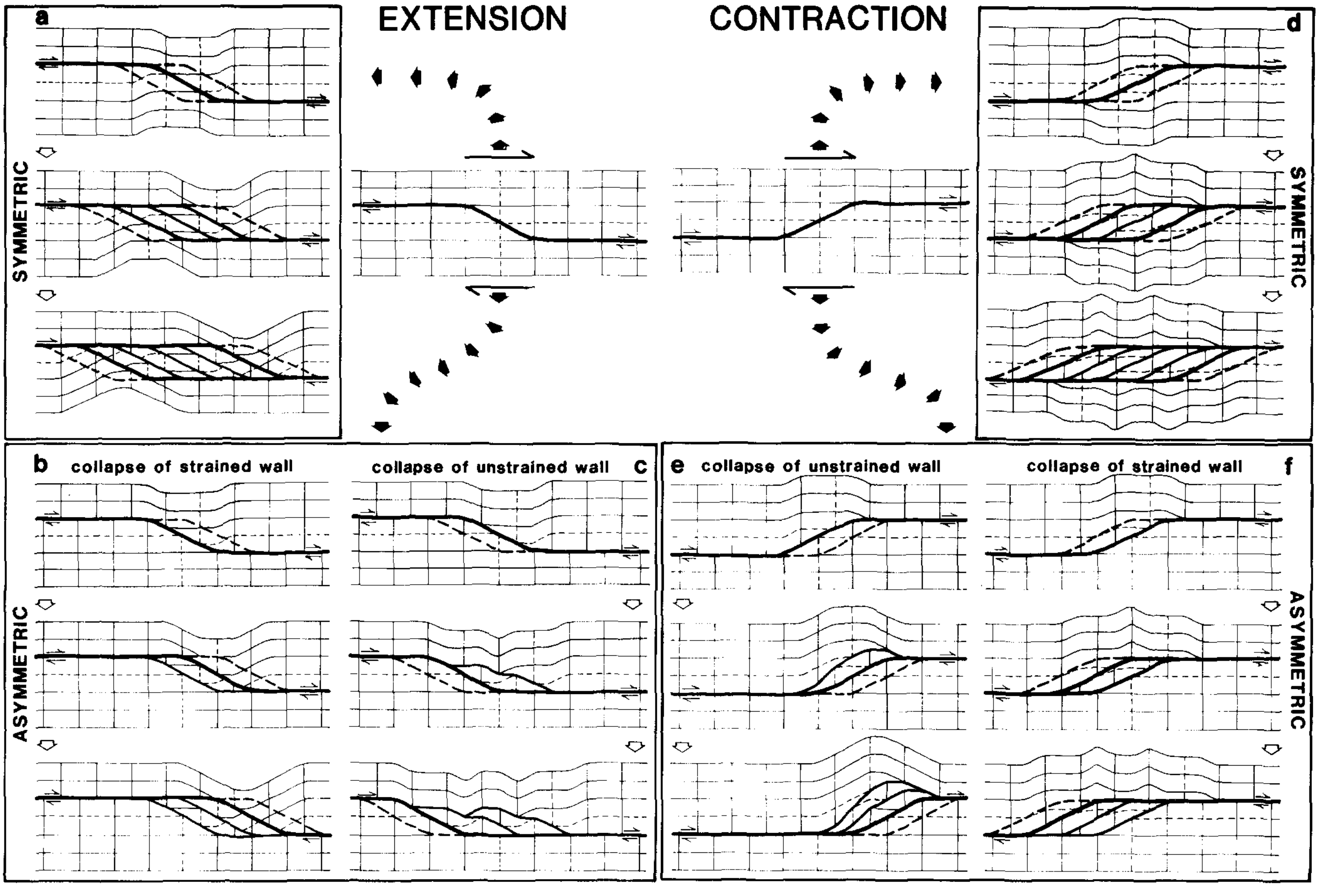

Fig. 4. Sequences of duplex development at bends in map views of a dextral strike-slip system. Grid shows displacements within and around horses. Thick lines are faults, dashed where incipient.

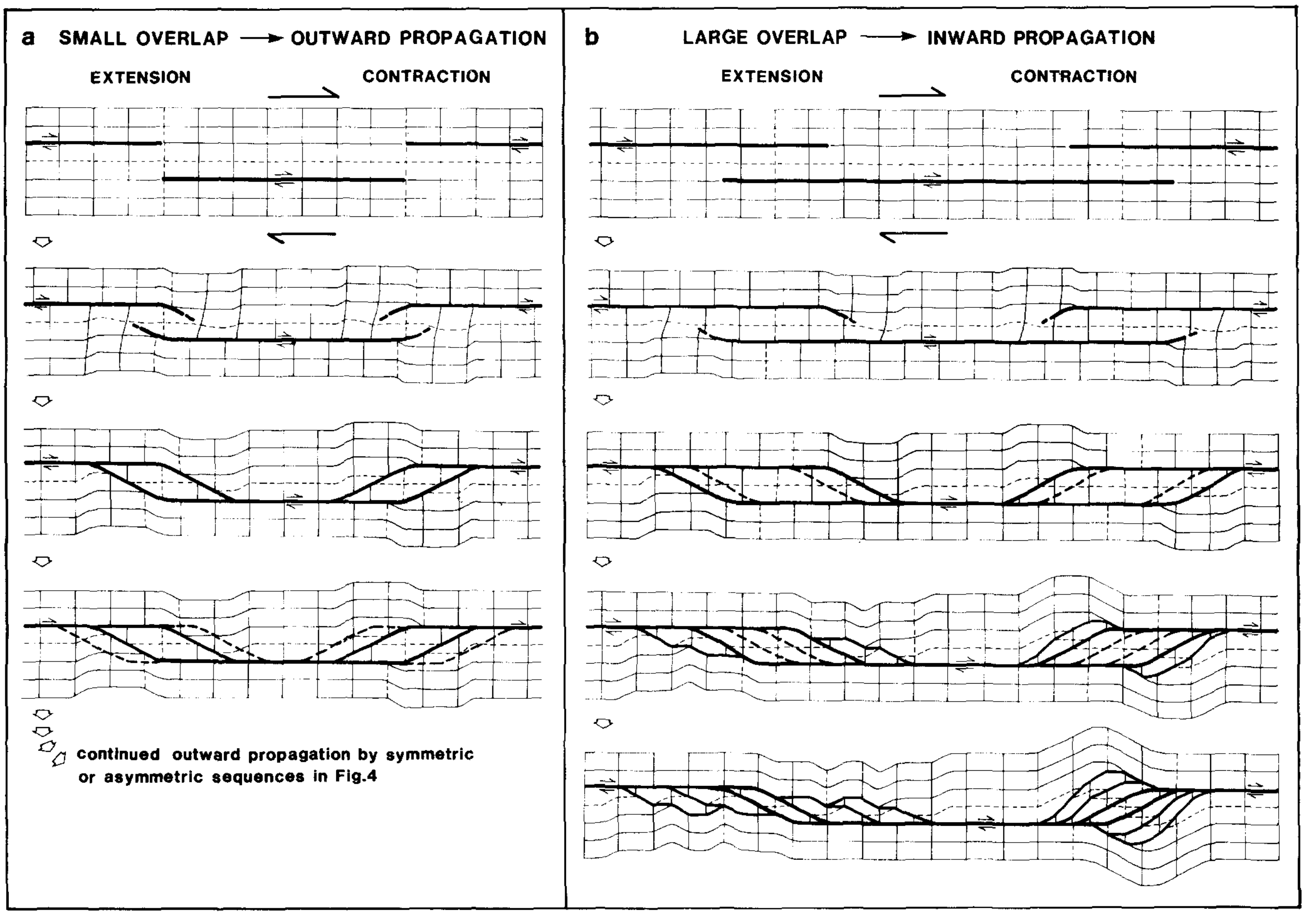

Fig. 5. Sequences of duplex development at offsets in map views of a dextral strike-slip system. Grid shows displacements in and around horses. Thick lines are faults.

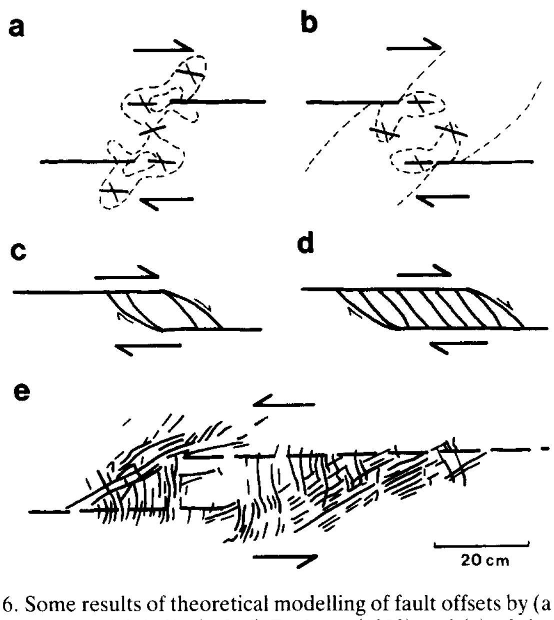

Fig. 6. Some results of theoretical modelling of fault offsets by (a & b) Segall & Pollard (1980), (c & d) Rodgers (1980) and (e) of claycake experiments of Hempton & Neher (in press). Solid lines are surface faults or (a–d) potential faults, coarse dashed lines (e) are subsurface faults, fine dashed lines (a & b) are contours of shear failure potential.

Duplexing on straights

Formation of duplex geometry is not restricted to marked bends and offsets. Experiments (e.g. Tchalenko 1970, Naylor *et al.* in press) show how grossly straight fault segments often comprise en-échelon conjugate Riedel shears (R and R′, Fig. 7a) at low displacement and how these become linked together at higher displacements by further shears (P and D, Fig. 7a) at a low angle to the slip vector. Duplex geometries may form by various interactions of these shears, but the experiments suggest two common modes. The first (Fig. 7b) involves the later P or D shears isolating a lozenge already cut by R shears. Such a duplex will necessarily have an extensional geometry. The second mode (Fig. 7c) involves imbrication by P shears of a lozenge between pre-existing R shears. This gives a contractional duplex. The second mode is kinematically similar to duplex formation between overlapping major faults at a large-scale offset (Fig. 5). The first mode is kinematically distinct from the bend or offset models in that the imbricate faults separating the horses pre-date the bounding faults to the duplex. Both types of Riedel duplex may be geometrically indistinguishable from ones formed at bends and subsequently shunted onto straights, though the Riedel duplexes may be smaller than the bend duplexes within any one fault system. Genetic classification of duplexes is further complicated because the Riedel duplexes may themselves induce and nucleate bends in the major faults, and because each duplexing process may operate simultaneously at a wide range of scales.

The claycake experiments by Tchalenko (1970) provide examples of both extensional and contractional Riedel duplexes (Figs. 8a & b). The sandbox experiments of Naylor *et al.* (1986) produced extensional Riedel duplexes made up of a series of lensoid horses

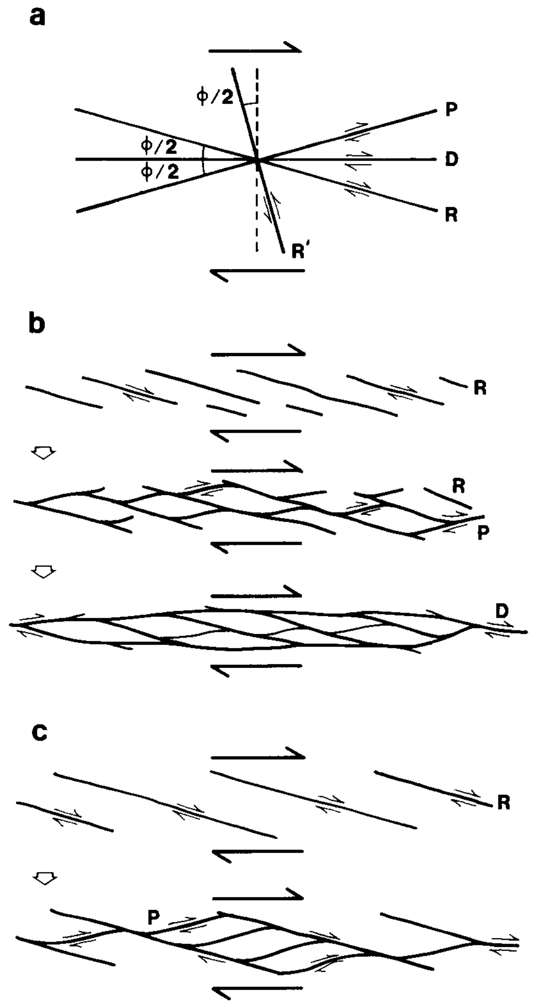

Fig. 7. (a) Ideal fault orientations in a dextral strike-slip system. (b & c) Sequences of duplex development on straights in map views of dextral strike-slip systems.

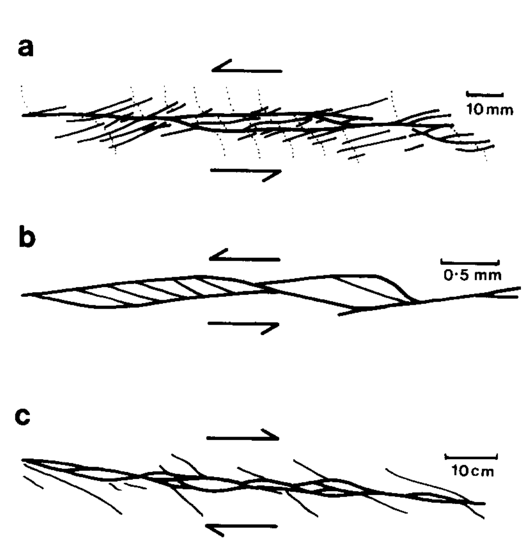

Fig. 8. Examples of duplexes formed on straights in (a, b) claycake experiments (Tchalenko 1970, figs. 4d, 10a) and (c) sandbox experiments (Naylor *et al.* in press, fig. 2e). Solid lines are faults, dotted lines are displaced markers.

(Fig. 8c, shear lenses of Naylor *et al.*). The active Dasht-e-Bayaz fault has a number of natural examples (e.g. Fig. 2b). A possible ancient example occurs along the Pontesford Lineament, Wales (location 2, Fig. 2d). This is an extensional duplex compatible with dextral displacement. It now occurs on a major releasing bend, but the small size of the horses compared with the bend size suggests that it may have originated at a smaller bend or as a Riedel duplex on a straight and was either shunted into its present position or overprinted by the developing large bend.

Shunting of duplexes

A duplex will stop forming when displacement ceases on its parent major fault. It is then *autochthonous* in that it is preserved in its original stratigraphic and structural context. Alternatively, a duplex may die due to changing geometry of the fault system whilst the parent fault is still active. The duplex may remain attached to one wall of the fault zone (Fig. 9a), with all the displacement taken up on the opposite bounding fault. With continued strike-slip this fault may juxtapose contrasting rocks against the duplex (Fig. 9b). However it retains its match with rocks on the other wall and in this sense is a *cognate duplex*. Later still (Fig. 9c) the same duplex, or one horse from it, may become attached (docked) to the opposite fault wall with the main strike-slip switching to a fault on its other flank. Continued displacement may finally remove any matching rocks (Fig. 9d) leaving an *exotic duplex* or horse totally isolated from any of its parent rocks and from its original structural context (Fig. 9d). Exotic duplexes and horses are analogous to 'far-travelled horses' in thrust systems (cf. Elliott & Johnson 1980).

This process of differential *shunting* along a strike-slip fault may be responsible for many of the small isolated lozenges of mismatching rocks in strike-slip systems (e.g. Crowell 1975). The shunting process is similar to one envisaged on a larger scale for transporting allochthonous terranes in orogenic belts (review by Schermer *et al.* 1984) and termed sidling by Dewey (1982).

An example of a cognate duplex occurs on the Pontesford–Linley fault, Wales (location 1, Fig. 2d). The duplex lithologically matches Precambrian sediments and volcanics on the SE side of the fault but large displacements on its NW boundary have juxtaposed contrasting Lower Ordovician sediments. Further north on the same fault (Fig. 2e) an exotic horse of the Precambrian volcanics is isolated between Lower Ordovician sediments to the NW and contrasting Upper Ordovician and Precambrian sediments to the SE. An example of a strongly exotic duplex is the Bastard slice on the North Pyrenean fault zone (Fig. 2k). The granulite facies basement rocks of the duplex only occur in quantity north of the fault zone some 30 km to the west. The duplex is bordered to the north by granites and to the south by calc-mylonites, both of relatively low metamorphic grade. During Early Cretaceous sinistral strike-slip movement on the fault the duplex must have formed against the Castillon massif, then transferred onto the southern fault wall and been shunted to its present position. A number of independent kinematic indicators, such as mineral extension directions in both the granulites and calc-mylonites, suggest that vertical movements are minor and that the duplex developed mainly as a result of lateral shunting (Fischer 1984).

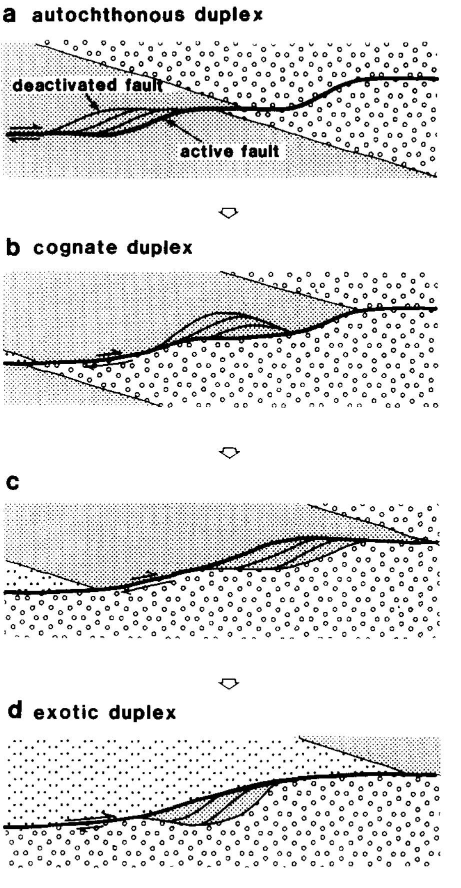

Fig. 9. Sequence of shunting of a duplex along a dextral strike-slip fault seen in map view.

NON-PLANE STRAIN DUPLEXING

Distributed subsidence and uplift

It has already been argued that most strike-slip systems have substantial differential vertical displacements which complicate the plane strain models discussed so far. The most obvious vertical effects are at bends and offsets, and two end-member methods have been drawn (Figs. 3d & e) of relieving the volume excess at restraining bends and volume deficit at releasing bends. The first method is by distributed uplift or subsidence of the bend and its surrounding area (Fig. 3d). This process is directly recorded on active faults, for instance the uplift at the 'big bend' of the San Andreas fault near Los Angeles (Fig. 10a) and more locally of an offset on the Coyote Creek Fault, California (Fig. 10b). It is predicted by elastic theory (Rodgers 1980) and modelled in

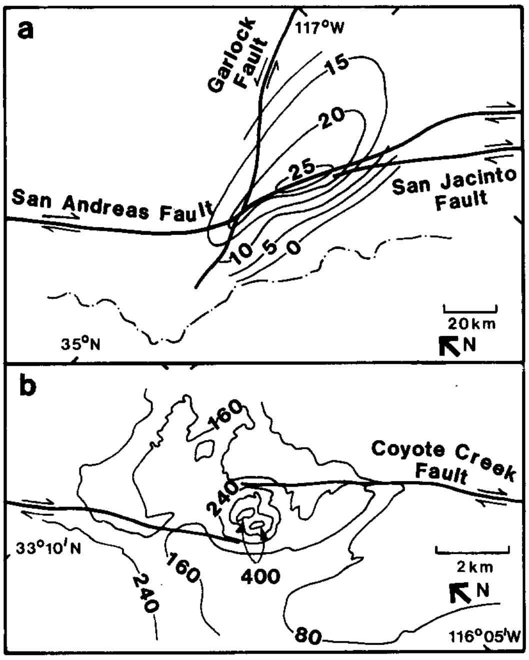

Fig. 10. Natural examples of uplift at bends on (a) San Andreas fault (in cm between 1959 and 1974, Castle *et al.* 1976) and (b) Coyote Creek fault, California (present elevations in feet, Sharp & Clark 1972).

claycake experiments (Hempton & Neher 1986). The maximum vertical displacement at a bend is about 10–15% of the magnitude of the strike-slip in the elastic model, 15–30% in the clay experiments, and averages about 10% at natural releasing bends (Hempton & Dunne 1984). The vertical movements may themselves be taken up on faults with a dip-slip component, departing from the end-member model of continuous deformation.

Local pull-aparts and push-ups

The other end-member process for accommodating volume changes is the discrete uplift or subsidence of the duplex (Fig. 3e). Active strike-slip systems show that subsiding pull-aparts form at releasing bends and uplifting push-ups form at restraining bends (e.g. Crowell 1973, Mann *et al.* 1983). Some of these areas have a clear duplex structure and others are isolated horses. Duplexing may play an important role in their geometric accommodation at depth.

A simple volume balance at a fault offset (Fig. 11) suggests that the instantaneous uplift or subsidence rate of a duplex could be of the same order as the slip rate on the bounding master faults. The controlling factor is the shape of the duplex, particularly the ratio of its vertical height to its along-strike length. 'Vertical height' will be determined by the depth to a low-dip detachment (see later) or to the branch-line of two downward-converging boundary faults. The calculation gives a maximum rate, since in natural systems some of the excess volume is accommodated by lateral bending of the fault walls and distributed uplift around the bend.

An example of a pull-apart with duplex structure is the Glynnwye Lake basin along the Hope Fault Zone, New Zealand (Fig. 2j). The duplex faults are normal oblique-

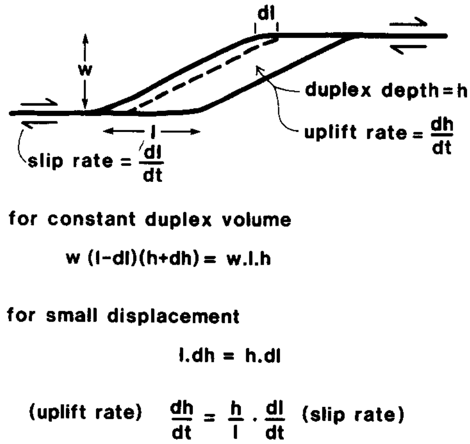

Fig. 11. Numerical estimate of rate of uplift (or similarly of subsidence) of a duplex or horse at an offset.

slip, dipping in under the pull-apart. Other examples have already been figured from Iran (location 3, Fig. 2h), California (Fig. 2f) and in theoretical models (Fig. 6b). The Gulf of Elat (Fig. 2c) is an extreme example of a pull-apart duplex floored by oceanic crust. The East Bay Hills area (Fig. 2g) is a push-up with contractional duplex geometry forming at a gentle offset between the Calaveras and Rodgers Creek faults. The duplex faults are reverse oblique-slip faults dipping in under the push-up. A further well-constrained example of inward-dipping boundary faults to a duplex is in the French Pyrenees (Fig. 2i).

Duplexes and flower structures

The inward-dipping geometry of faults under both pull-apart and push-up duplexes suggests that the faults may converge at depth into a single shear zone (Fig. 12). In vertical section the faults define a flower structure (Sylvester & Smith 1976). This model is compatible with the duplex geometry observed in some seismic profiles through strike-slip flower structures (e.g. Harding 1983, 1985). Pull-aparts may commonly be underlain by negative (normal faulted) flower structures and push-ups by positive (reverse faulted) flower structures.

A link between flower structures (or 'tulip structures') in section and 'Riedel shear lenses' (either duplexes or isolated horses) in plan view is seen in sandbox experiments (Naylor *et al.* in press). Each Riedel shear has a helicoidal form (similar to that in Fig. 12) so that at depth they unite into a single steep fault zone. The downward converging fault geometry can form on straights with no bulk shortening or extension normal to the fault trace. Transtension suppresses the en-échelon nature of the Riedel shears whereas transpression increases the angle between the Riedels and the basement fault trend (Naylor *et al.* in press). This relationship is also predicted theoretically (Sanderson & Marchini 1984).

Low-dip detachments

An alternative geometry to, or a component of, flower structures for maintaining three-dimensional strain com-

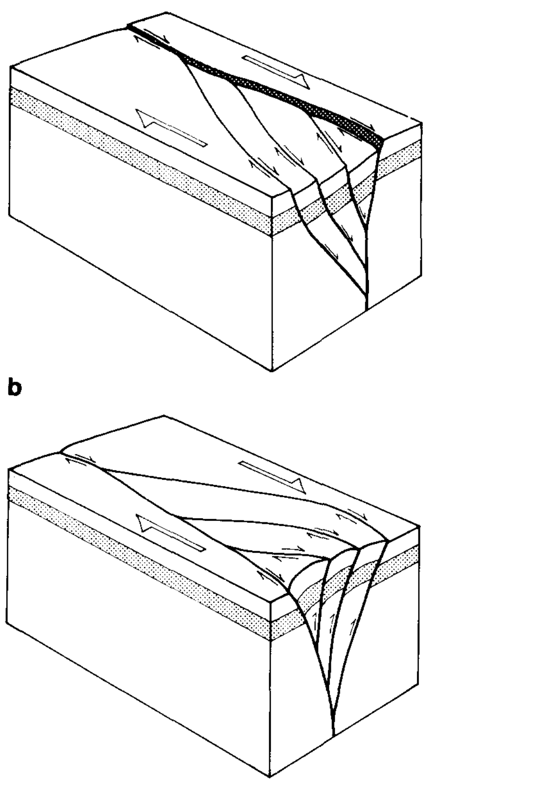

Fig. 12. Postulated three-dimensional form of (a) an extensional duplex (showing negative flower structure) and (b) a contractional duplex (showing positive flower structure).

patibility in the upper levels of the crust is for steep strike-slip faults to be associated with or root in low-dip faults or shear zones. These faults allow various levels in the strike-slip system to move over one another and to rotate [strike-slip *flaking* of Dewey (1982)]. These kinematically necessary flats are analogous to lateral ramps or transfer faults in dip-slip systems. Flat detachment zones must necessarily delimit strike-slip systems at depth as they do dip-slip systems. Two possible sites are a mid-crustal discontinuity (e.g. Sibson 1983) or a sub-lithospheric zone related to a transform fault zone.

Complex duplex subsidence and uplift

The expected location of extensional duplexes at pull-aparts and contractional duplexes at push-ups only holds at low displacements. Large displacements allow along-strike shunting of duplexes so that, in the extreme case, a contractional duplex might eventually dock at a rrleasing bend and be reactivated as a pull-apart. The vertical displacements of duplexes on straights will depend on a variety of factors: the regional stress state across the fault zone and local effects, particularly from bends and duplexes migrating along adjacent fault strands. The tendency of duplexes and of isolated fault lozenges to uplift and subside alternately as they move along a strike-slip system has been called *porpoising* (Crowell & Sylvester 1979).

IMPLICATIONS OF THE DUPLEX MODEL

Balanced sections

The technique of constructing cross-sections by balancing deformed against restored sections is well established in thrust belts (e.g. Hossack 1979, Elliott 1983) and has now been applied to normal fault systems (e.g. Gibbs 1984). These sections are drawn in the plane perpendicular to the faults that also contains the fault slip vectors. The assumption is that material points remain within the plane of the section during deformation, and therefore that the area of a deformed unit exactly balances its undeformed area. Some oblique sections can be balanced if the structures are cylindroidal and it is assumed that the amount of material leaving the plane of the section equals the amount entering the section.

For dip-slip fault systems the appropriate section to balance is vertical. The analogous section for strike-slip systems is horizontal. Map views of such systems can be balanced (e.g. Figs. 4 and 5) if displacements are purely horizontal. However, natural strike-slip systems demonstrate the importance of vertical displacements, as do theoretical and physical models. If these movements, for instance the subsidence and uplift of duplexes or isolated fault lozenges, occurred on precisely vertical faults then area balancing might still be valid because each fault lozenge would maintain a constant cross-sectional area as it moved through the map section. The invalidating factor is that the faults often converge downwards as flower structures, so that subsiding lozenges will progressively increase in map-view area and uplifting lozenges decrease. There is no reason for these two effects to balance out on any one section.

It is tempting to area balance vertical sections through strike-slip systems, for example from seismic profiles. This will only be valid if material is moving into and out of the section at the same rate, for instance in an ideal ductile shear zone or one comprising faults exactly parallel to the fault zone strike. This condition is most unlikely given the complex braided fault pattern of most strike-slip systems. In particular it is invalidated by differential shunting of duplexes along strike-slip faults.

Many balanced sections through apparent dip-slip systems have been constructed without regard for the possible strike-slip component. Woodcock (1986) argues that about 60% of orogenic belts may have had a significant orogen-parallel strike-slip component.

Kinematic vs dynamic models

Previous approaches to strike-slip fault systems have been essentially dynamic, considering ideal orientations of faults, folds and fabrics with respect to the stresses or elastic strains within the fault zone (e.g. Tchalenko 1970, Wilcox *et al.* 1973, Rodgers 1980). This has been a profitable approach and gives a good match with natural structures formed in zones with small displacement. However, the theory applies to isotropic rocks, which is why it is not so appropriate to dip-slip systems whose lower-angle faults are more affected by the antisotropy of the sedimentary bedding. Only rarely (e.g. Crowell 1974) has it been appreciated that in strike-slip systems the early, ideally oriented fractures themselves introduce an anisotropy which increasingly influences the geometric evolution of the system. After only modest displacement the system is pervaded by fractures in a wide range of orientations (e.g. experiments by Tchalenko 1970). It then evolves more by slip on suitably oriented old fractures than by propagation of new ones. The control is not so much dynamic as a kinematic need to rearrange the fault blocks in compatibility with the imposed boundary conditions. The duplex concept is one of a series of kinematic patterns which need to be identified before the complexities of strike-slip fault systems can be understood.

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