experimental uncertainty; that is within about 1°. This suggests that the hypothesis is substantially correct and may be significant in accounting for the variable attitudes in natural en échelon systems.

Mass transport, fluid flow and foliation development. M. A. Etheridge,* V. J. Wall,† S. F. Cox† and R. H. Vernon,‡ * Bureau of Mineral Resources, P.O. Box 378, Canberra, A.C.T., Australia, 2601, † Department of Earth Sciences, Monash University, Clayton, Victoria, Australia 3168, ‡ School of Earth Sciences, Macquarie University, North Ryde, New South Wales, Australia, 2113.

Several independent lines of evidence attest to the importance of mass transport over distances of tens of metres to kilometres during foliation development, especially at low metamorphic grades. The amount and distance of mass transport have profound implications for the transport process. In particular, diffusive transport via a standing fluid is unable to compete with advective solute transport in a mobile fluid. Additionally, the mass of solute moved during foliation development requires fluid volumes that are orders of magnitude too large for a single-pass system. We propose that a multiple-pass system is accomplished largely by thermal convection. Simple Rayleigh/Darcy modelling of a regional metamorphic terrain indicates that convection is feasible at permeabilities greater than 10^{-17} m^2. Permeability enhancement during deformation and metamorphism arises from grainscale and larger cracking, due largely to stress- and strain-rate incompatibilities at high fluid pressure, and to volumetric strains due to devolatilization reactions.

Since diffusion is not the rate-controlling transport process in this scenario, creep laws of unfamiliar form may apply during foliation development. We present one possible model in which deformation rate is controlled largely by the rate of fluid flow (i.e. by permeability and the advective driving force). This model has an unusual temperature dependence that may depart significantly from the usual Arrhenius form.

The geometry and role of normal faulting in sedimentary basin development. M. A. Etheridge, Bureau of Mineral Resources, P.O. Box 378, Canberra, A.C.T., Australia, 2601.

Lithospheric extension is a key process in basin formation, and it generally results in normal faulting in the upper crustal floor to the sedimentary sequence. The geometry of such faults provides a most important constraint on the kinematics of the crustal deformation accompanying basin formation, and is therefore a key element in thermal and subsidence modelling. The geometry of extensional normal faulting has recently been treated in some detail, and this paper concentrates on the following specific aspects.

(1) All forms of rotational normal faulting demand substantial penetrative deformation of the fault blocks, especially at moderate to large extensions. Consideration of the geometry of undeformable models of the planar and circular listric end-members indicates that the latter requires considerably more penetrative deformation per unit extension, and that the planar or 'domino' style may therefore be energetically favoured.

(2) Calculation of extensional strain from the geometry of planar normal faults is straightforward. However, in the listric case, the computed extension is dependent on the manner in which the penetrative deformation is accomplished. It is shown that a previous model, in which extension by listric faulting is substantially less than that by planar faulting, is not broadly applicable. In fact, for $\beta > 1.5$, the computed extensions for planar or a more realistic listric model are very similar, and the block-top geometry method used for planar rotational faults is broadly applicable to curved fault geometries.

(3) Mechanical, thermal and subsidence modelling of sedimentary basins require an accurate kinematic framework, and this is best provided by the major fault geometry. Two seismic sections from the BMR 1982 Bass Strait Seismic Survey illustrate a number of simple kinematic principles that need to be taken into account when interpreting such sections and modelling sedimentary basin formation.

Problems of volume loss, fabric development and strain determination in low-grade pelitic rocks: Martinsburg Formation, U.S.A. D. R. Gray, Department of Earth Sciences, Monash University, Clayton, Victoria, Australia, 3168, and T.O. Wright, Earth Sciences Division, National Science Foundation, Washington, D.C. 20550, U.S.A.

Determination of volume changes in deformed rocks is problematic and has led to controversy about volume-loss vs constant-volume deformation models for cleavage development in low-grade pelitic rocks. Most determinations have involved chemical analysis, although a simpler more efficient method uses graptolites on bedding surfaces. The effect of volume loss in strain analyses in slates is another closely related problem, since most strain gauges cannot discriminate between volume-loss and constant-volume processes.

These combined problems have been confronted within a belt of Martinsburg shale in the Great Valley of northern Virginia and Pennsylvania. This belt shows ubiquitous development of a spaced slaty cleavage. The rocks contain both graptolites and pressure-fringes on framboidal pyrites. Preliminary comparison of strain data from both markers suggests that where principal extensions are low, volume losses due to pressure dissolution are high. Similarly, where principal extensions are higher, volume losses appear lower. Volume losses up to 50% occur in some parts. Chlorite fibre-growth patterns on the pyrite require either plane strain or constriction. Morphologically similar hand specimens from widely separated geographical locations show markedly different partitioning of strain. This requires different deformation mechanisms at the grain scale and suggests varying contributions of these along the strike of the belt during cleavage development.

Boudinage and tension fracturing during bulk simple shearing. L. B. Harris, Centre Armoricain d'Etude Structurale des Socles (CNRS), Université de Rennes, 35042 Rennes Cédex, France.

Field and experimental studies of boudinage and tension fracturing during bulk simple shearing have shown that boudin necklines and tension fractures may develop at an oblique angle to the maximum extension directions. Boudins are displaced along shear bands of normal fault geometry consistent with the bulk sense of shearing. Minor conjugate shear bands, along which normal movement takes place, of opposite sense to the bulk shearing are also developed at an early stage between boudins.

Progressive and polyphase deformation of the Schistes Lustrés in Cap Corse, Alpine Corsica. L. B. Harris, Centre Armoricain d'Etude Structurale des Socles (CNRS), Université de Rennes, 35042 Rennes Cédex, France [present address: Geology Department, University of Western Australia, Nedlands, Australia 6009].

In Cap Corse, progressive deformation during Late Cretaceous obduction of the ophiolitic Schistes Lustrés (*sensu lato*) as a pile of imbricate, lens-shaped units during blue-schist facies metamorphism is non-coaxial. Two zones are recognized: a lower series emplaced towards the W is overlain by a series emplaced towards the SSW in western Cap Corse. Equivalent structures (differing only in orientation) occur in both zones. The change in thrust direction is responsible for local refolding and reorientation of previously formed structures parallel to the new stretching direction immediately below the thrust contact between the two zones and within localized shear zones in the underlying series.

Both zones are refolded about E-overturned F_2 folds trending between 350 and 025°. Local minor E-directed thrusts occur associated with F_2 folds. This second deformation of Middle Eocene age is considered to be related to the backthrusting of an overlying klippe containing gneisses of South Alpine origin, and is followed by a third Late Eocene phase of upright 060°-trending F_3 folds accompanied by greenschist facies metamorphism.

Influence of basement structures, pore fluids, and stress refraction on en échelon veins, Burdekin region, Queensland. E. J. Heidecker, Department of Geology and Mineralogy, University of Queensland, St. Lucia, Queensland, Australia, 4067.

Excellent exposures along the Burdekin River and its tributaries provide special opportunities to detect controls upon the many styles and generations of veins of a major gold and mineral field. Well-defined unconformities help appreciation of the role of older structures in deducing tectonic chronologies from fabrics.

Reference exposures of Middle Devonian limestone between 'Fletcher View' and the Big Bend north of Charters Towers illustrate different types of en échelon vein arrangements and variations in the styles of veins of different ages and compositions. A sheet of limestone rests unconformably upon a pre-Devonian granodiorite basement dissected by older dykes, veins and a NW-trending foliation. Vein fabrics differ markedly from outcrop to outcrop. Patterns emerge in more extensive vein fabrics. These patterns indicate correspondence between younger vein fabrics and complex basement fabrics dominated by NW-trending foliation. A plot of en échelon vein directions reveals that those to the left of the foliation direction are dominantly sinistral and that those to the right are dominantly dextral. These relationships and a range of angular relationships point to a complex model for en échelon arrangements in which Riedel 1 and 2 fractures, as well as tensional fractures are influenced by older basement structures.

An early generation of limestone veins is darkened by inclusions of sulphuretted hydrocarbons. The terminations of these veins are distinctively 'horsetailed' unlike the simple terminations of later, white carbonate veins. A hypothesis for these style differences is that they are responses to changes in pore-fluid pressures and compositions.

Another reference area for veins lies along the Broken River, a tributary of the Burdekin River 150 km west of the Big Bend area. En échelon veins have formed in a quite different tectonic environment within a thick folded sequence of Silurian limestones. Stylolites indicate far greater volume changes than in the Big Bend reference area and also indicate systematic refraction of stress trajectories towards the normals to en échelon arrangements. Contrary refraction about conjugate en échelon arrangements is commonly sufficient to bring gash veins of one arrangement into close parallelism with the en échelon direction of a conjugate set.

Structural analysis of the Broken Hill Block. B. E. Hobbs* N. Archibald,* M. A. Etheridge† and V. J. Wall,* * Department of Earth Sciences, Monash University, Clayton, Victoria, Australia, 3168, † Bureau of Mineral Resources, P.O. Box 378, Canberra, A.C.T., Australia, 2601.

The aim of this paper is to discuss the philosophies involved in the interpretation of multiply deformed terrains with special emphasis, as an example, on the Broken Hill Block. A structural interpretation of the area is presented involving four periods of deformation each associated with the development of macroscopic folds. In addition, later structures associated with retrograde schist zones are developed. Earlier workers have used a classical (Weissian) approach employing mesoscopic fabric elements which have been assembled into a chronological scheme and then used to interpret the macroscopic structure. This led to a macroscopic picture of essentially upright folds superposed coaxially on earlier nappe-like folds. The present study employs the mapped outcrop patterns combined with the spatial distribution of structural facings to identify the macroscopic structure. A step is then made backwards in scale from the macroscopic to mesoscopic to discuss the significance of the mesoscopic fabric elements. On this basis, the regional structure consists essentially of early, inclined to recumbent folds with later upright folds superposed almost at right angles to the trend of the earlier axes. This leads not only to a difference in macroscopic structure between the two approaches but important differences in mesoscopic interpretations arise as well.

Multiple deformation in the Dales Gorge Member of the Lower Precambrian Hamersley Group, Western Australia. R. C. Horwitz, C.S.I.R.O., Division of Mineralogy, Floreat Park, Western Australia, Australia, 6014.

Analyses of structures in the Hamersley Province indicate the existence of several directions of folds and faults. The WNW-oriented Hamersley Synclinorium is parallel to smaller en échelon folds. A conspicuous E–W trend is outlined by axial culminations of anticlines and two complementary en échelon sets strike NE and NW.

Two complementary fault or joint systems, largely restricted to the Archaean group are known to have acted during the transgression of the Fortescue Group. One strikes E–W, the other is arcuate, striking generally N in the south and swinging to NNE in the north. Another set of complementary faults essentially frame the Province to the southwest and southeast; one swings from NW in the south to N in the west; the other strikes about NE.

Isopach maps, compiled for each of the alternating 33 macrobands of the Dales Gorge Member of the Brockman Iron Formation and for groupings of them, were analysed and are interpreted as interference patterns of multiple axes of thickening and thinning. Despite an apparent haphazard distribution of thicknesses in the successive macrobands, most thickness axes are only displaced in a minor way from one to the next. The trends of thickness parallel and follow the distributional biases of the WNW (regional fold) the E–W (fold and fault) and the N to NNE (fault in basement) structural trends. The distribution and dominance in BIF or S macrobands indicate that thickness variations in the Dales Gorge Member result from several features with a contribution from a form of compaction of slumping during sedimentation engendered by faults in the basement.

Tectonic evolution and fabric development of the Arunta Complex in the Harts Range, Central Australia. P. R. James, P. Ding, R. W. Lawrence, A. R. Martin, L. Rankin and G. P. Scales, Department of Geology and Mineralogy, The University of Adelaide, Adelaide, South Australia, Australia, 5000.

High-grade metamorphic rocks of the Arunta Block in the Harts Range Area have been divided into two major groups according to lithology and structure. An underlying crystalline basement has been recognized as having a more complex tectonothermal evolution than its structurally overlying supracrustal cover sequence. The basement is comprised predominantly of layered felsic and mafic gneisses which have a complex history of three isoclinal fold events, BD_1, BD_2 and BD_3, followed by tight inclined to upright folds (BD_4) trending in a NE direction. All folds deform a high-grade, layer-parallel fabric which is intensified by the folding. Included with the basement is the Entia gneiss complex (an inlier with the Entia Dome), the Oonagalabi gneiss complex (an isoclinal fold of remobilized basement represented by the Oonagalabi Tongue) and undifferentiated gneisses in the south of the area. Basement thrusts (BT) are confined to the western portion of the Oonagalabi Tongue.

Structurally overlying the basement are the cover rocks of the Irindina supracrustal assemblage (predominantly pelitic gneisses, but including calcareous rocks and quartzites) and of the Harts Range meta-igneous complex (predominantly mafic amphibolites, but including the Entia anorthosite). Both units are complexly folded by three isoclinal events CD_1, CD_2 and CD_3. A thrusting event CT, responsible for décollement surfaces along many of the lithological contacts within the cover sequence, occurred between the last two of these ductile events, and stacked the cover sequence into a series of nappes.

Basement and cover were juxtaposed by a major semi-ductile thrusting event, HRT_1, and then both cover and basement were isoclinally folded during HRD_1 at the commencement of the Harts Range orogenic event. Two thrusting events HRT_2 and HRT_3 were responsible for the tectonic emplacement of the megacrystic Bruna granitic gneiss, which now separates basement and cover throughout much of the Harts Range Area. HRT_2 was isoclinally folded during HRD_2 and HRT_3 during HRD_3. Subsequently the area was deformed by less intense open folds which resulted in the complex major basin-and-dome outcrop style.

Microstructures and sequence of deformation along the Norumbega Fault Zone, Eastern Maine, U.S.A. T. D. Johnson and D. R. Wones, Department of Geological Sciences, 4044 Derring Hall, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 24061, U.S.A.

The Norumbega Fault Zone, a NE-trending zone of ductile and brittle deformation (Devonian or younger), consists of about five distinct fault traces. All lines of evidence suggest dextral and south-up oblique shear in the major vertical NE-trending shears, with associated conjugate sinistral shears in some areas. The affected lithologies are phyllite, schist, felsic gneiss, felsic granite, mafic granite and syenite.