Hydrofracture dilatancy and the development of quartz-vein arrays in the Wattle Gully Fault Zone, Victoria. S. F. Cox,* M. A. Etheridge,† V. J. Wall,* and T. F. Potter,‡ * Department of Earth Sciences, Monash University, Clayton, Victoria, Australia, 3168, † Bureau of Mineral Resources, P.O. Box 378, Canberra, A.C.T., Australia, 2601, ‡ Chewton Gold Associates, Chewton, Victoria, Australia, 3451.

Hydrofracture dilatancy associated with faulting at high fluid pressures has generated major quartz-vein systems in many reverse fault zones which developed during regional deformation and low-grade metamorphism in the Bendigo Trough, Victoria.

Within the Wattle Gully Fault Zone dilatancy has occurred both within faults and in hydraulic fracture arrays adjacent to faults. The overall geometry of quartz-vein arrays reflects development in a stress regime in which the far-field σ_1 axis was oriented approximately E–W, and the far-field σ_3 axis was approximately vertical. Complex vein geometries adjacent to many faults reflect the influence of various factors including local stress reorientation, vein rotation and mechanical anistropy of the wall rocks.

Vein growth typically involved cyclic crack–seal growth histories. Microstructures indicate that vein growth involved up to 2×10^3 growth increments per centimetre of vein width, and that both sub-critical and unstable crack growth mechanisms were involved in the development of fracture arrays.

Evidence from the Wattle Gully Fault Zone points to a faulting mechanism in high fluid-pressure regimes in which the cyclic development of hydrofracture dilatancy accompanied cyclic build-up of fluid pressure and shear stress prior to slip events. Shear failure can occur in response to increasing fluid pressure reducing the shear strength of the fault zone to the level of the tectonic shear stress. Slip events are expected to be accompanied by rapid, local relief of fluid pressure and shear stress, and to result in 'fluid-loss hardening' of the fault zone, as well as partial collapse and sealing of dilatant fracture arrays.

The Bermagui megakink and associated structures. T. J. Cudahy, School of Earth Sciences, Macquarie University, North Ryde, New South Wales, Australia, 2113.

The coastal greywackes and slates in the easternmost Lachlan Fold Belt are deformed into tight, upright folds with an associated well-developed axial-plane cleavage: the bedding and cleavage forming a subvertical anisotropy available for later deformation. The last deformation was a N–S compression, resulting in a variety of structures, for example: megakinks (tens of kilometres); second-order kinks (hundreds of metres); outcrop-scale kinks and buckles (centimetres to metres); microfolds and pressure-solution surfaces (seen in thin section); joints, faults and shear zones.

Outcrop-scale kinks developed in all megakink and second-order kink domains, and calculated compression directions indicate that the principal compression axis, σ_1, was subhorizontal and parallel to the vertical anisotropy, even though some domains are oriented up to 90° to the regional meridional trend. The simplest model of compression is that all the domains were parallel when the outcrop-scale kinks formed, and were later rotated into their present megakink form. Furthermore, the variation in the relative proportions of sinistral and dextral kinks around the Upper Devonian synclinal keel (a dominance of sinistral kinks in the eastern periphery and dextral kinks on the western side) suggest a refraction of the principal compression axis, such that σ_1 remained horizontal but became more oblique to the synclinal keel.

The Upper Devonian synclinal keel was not significantly deformed during kinking (apart from jointing), and caused an area of high strain to develop around its periphery. This high-strain zone is expressed by concentrations of outcrop-scale kinks and the second-order Murrah kink zone. Overprinting relations enabled the following order of structural events to be determined: (1) outcrop-scale kinking and jointing; (2) formation of sinistrally and dextrally oriented cleavage and (3) mega- and second-order kinking.

Problems of structural correlation in accretionary prisms. I. W. D. Dalziel, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964, U.S.A.

Metamorphic and sedimentary rocks of the Scotia Ridge represent material accreted to the West Antarctic margin of Gondwanaland before and after fragmentation of the supercontinent. The metamorphic complexes include rocks of oceanic affinities and are interpreted as having been carried to considerable depths (>20 km) beneath an accretionary prism. The sedimentary strata are interpreted to have been deposited in trench-slope basins.

The metamorphic rocks display a remarkably similar history of polyphase ductile deformation along several hundred kilometres of the continental margin. Yet some of them were deformed prior to the Late Jurassic or Early Cretaceous and others may be as young as Cenozoic. The sedimentary sequences are everywhere deformed by tight to sub-isoclinal asymmetric 'main phase' folds with an accompanying axial-plane cleavage, and also by subsequent 'late phase' open folds and kink bands. Yet they were probably deposited in several discrete basins.

The problems raised by these field relations and other data with regard to structural correlation in accretionary prisms were discussed.

A multiply deformed terrain in southern British Columbia: exploration for Ag–Pb–Zn sulphide deposits. G. J. Dickie, Minequest Exploration Associates Limited, 311 Water Street, Vancouver, B.C. V6B 1B8, Canada.

Numerous sulphide deposits bearing Ag–Pb–Zn occur in a sequence of slightly metamorphosed sedimentary and volcanic strata of Late Palaeozoic age in south-central British Columbia. The deposits are stratiform in character but are discontinuous. The enclosing strata have a strongly developed foliation sub-parallel to lithologic boundaries and regional and detailed mapping shows that the foliation is parallel to the axes of F_1 isoclinal folds. Bedding is at a high angle to the foliation at the fold hinges. Sulphide beds show some attenuation on the F_1 limbs and consequent thickening at the fold hinges. A second set of folds, F_2, with axes oriented E–W has also produced thickening of sulphide beds in the hinge areas of minor folds, emphasizing the concentration of sulphides in structurally controlled positions. Minor thrust faults along and across the foliation occur on the small scale and are assumed to exist at a larger scale thereby explaining some discontinuities in stratigraphy. Third-phase folds, F_3 are open with N–S axial planes spatially related to normal faults and have no significant effect on sulphide disposition. In this structural setting, the most likely location for a major sulphide accumulation is at the culmination of a large F_1 fold. Smaller deposits could be localised within the hinge areas of F_2 folds. The target shape for sulphide deposits is a linear plunging body and exploration patterns have been directed accordingly.

Attitude variation of en échelon fractures in generalized Riedel experiments. D. W. Durney, School of Earth Sciences, Macquarie University, North Ryde, New South Wales, Australia, 2113.

One of the interesting characteristics of en échelon fracture systems is the wide range of dihedral angles they display between individual fractures and the plane of the parent array. For en échelon veins this is from almost 0° up to about 85°. This note reports a series of simple experiments which are designed to test the writer's theoretical prediction that the angle of fracture propagation is variable and depends on the degree to which the material in the shear zone dilates or contracts during the deformation (incremental dilational shear hypothesis). For dextral zones the relationship is

$$\phi^{\delta} = \psi^{\delta}/2 - 45° \qquad (-90° < \phi < 0°)$$

where ϕ^{δ} is the principal incremental shortening direction and ψ^{δ} is the incremental displacement direction, given by

$$\tan \psi^{\delta} = \delta\Delta/\delta\gamma.$$

$\delta\Delta/\delta\gamma$ is the ratio of incremental volumetric or area strain to incremental shear. (In plane-strain conditions this is the dilatancy.)

The reported experiments are based on W. Riedel's clay-boards experiments of 1929, with the important additional facility of a controlled, oblique, displacement path (ψ^{δ}). En échelon extension fractures were reproduced under three different values of zone displacement angle: $\psi^{\delta} = +45°$ (divergent shear), $\psi^{\delta} = 0°$ (simple shear) and $\psi^{\delta} = -45°$ (convergent shear). In all three runs the observed fracture propagation angles fit the predicted angles (ϕ^{δ}) to within the limits of 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.