METAMORPHISM, FOLDING AND PLUTONISM IN THE WAGGA METAMORPHIC BELT OF N.E. VICTORIA

R.J. Rogerson

Department of Geology and Geophysics,
University of Sydney, NSW 2006

Structural and metamorphic studies carried out in N.E. Victoria show that the classic low-pressure metamorphism described previously by Vallance (1953, 1967), Joplin (1942, 1944, 1947) and Guy (1968) consisted of a complex interaction of metamorphic events, compressional periods and granite intrusion. Large gaps exist on maps showing the geographical distribution of zonal index minerals due to burial by younger rocks and lack of study (Fig. 1).

At least three regional metamorphic events and five periods of deformation affected N.E. Victoria and S.E. New South Wales during the Benambran Orogeny (Fig. 2). Deformation

\[ D_1 \] produced tight to isoclinal 080°-trending \( F_1 \) folds which were overprinted by 150°-trending \( F_2 \) folds referable to the second deformation \( D_2 \). \( F_2 \) folds are marked by a strong axial-plane crenulation cleavage \( S_2 \), and an isoclinal style. The \( F_3 \) trend is dominant in the Ordovician rocks of the Wagga Metamorphic Belt, but \( F_1 \) trends are preserved in a number of localities, including Albury (Hellman, 1973), and in the Tallandoon area of N.E. Victoria. \( D_2 \) produced microcrenulations and kinks with axes trending roughly east-west. Deformation \( D_{NNW} \), consisting of faults trending NNW, overprinted \( S_2 \) and affected the Corryong, Koetong and Lockhart Granites. \( D_{NNE} \) produced faults trending to the NNE, which in places separate rocks of markedly different metamorphic grade. The Talgarno Fault has this trend and affects Upper Devonian rocks. The three compressive deformations \( D_1 \), \( D_2 \) and \( D_3 \) are recognized by overprinting criteria exhibited regionally in N.E. Victoria, but it is not known whether \( D_2 \) occurred contemporaneously throughout the whole region. Furthermore, although \( D_{NNW} \) overprints structures referable to \( D_2 \), the relationships between \( D_{NNW} \) and \( D_3 \), and between \( D_{NNW} \) and \( D_{NNE} \) are incompletely known at present.

Textural relationships observed in thin-section indicate that two prograde events, and at least one retrograde metamorphic event, affected N.E. Victoria. \( M_1 \), the principal metamorphic pulse, produced andalusite and cordierite at medium grades, and at several localities, viz. east of Bethanga (Williams, 1969; Rogerson, 1974), Batlow (Bradley, 1968) and Tallandoon (Rossiter, 1973), staurolite has been described from iron-rich schists. The Bethanga schists exhibit staurolite porphyroblasts with a syntectonic \( F_2 \) spiral form and pressure shadows which frequently contain pinitised cordierite porphyroblasts, while the other cordierite porphyroblasts in the same thin-section clearly overprint \( S_2 \). The poikiloblastic nature of the cordierite grains in the pressure shadows suggests they nucleated late in the development of the pressure shadows, or afterwards. Both these occurrences of cordierite are assigned to a second metamorphic period \( M_2 \), which may have been of lower pressure than the first if staurolite became unstable in post-\( D_2 \) times. Some marginal breakdown of staurolite to muscovite has occurred, and, in addition, it is probable that mineralogical adjustments to the matrix occurred also to facilitate the nucleation of \( M_2 \) products. Andalusite, cordierite, biotite and chlorite porphyro-
blasts overprinting \( S_2 \) in other areas (Guy, 1968) have also been assigned to \( M_2 \). The non-appearance of staurolite in most rocks could be ascribed to the lack of suitable initial compositions. A regional low-grade metamorphic event \( M_3 \) post-dated \( M_2 \), and retrogressed previously developed minerals. Smart (1975) recognised a retrograde event between the events referred to here as \( M_4 \) and \( M_2 \).

Current work is aimed at identifying the timing of granite intrusions within this framework by the overprinting of structural elements on various granites and their attendant contact metamorphic aureoles. The Lockhart Granite, exposed near Tallangatta, is a cordierite-rich, two-mica granite displaying a marked mineralogical heterogeneity, and, in one place, a crude gneissic foliation trending between \( 060^\circ \) and \( 100^\circ \). Cataclastic effects attributable to \( D_{NW} \) occur along part of its eastern margin, but most of the mass away from this area is dominated by a flow foliation trending \( 150^\circ \). This granite has the chemical features of the Cooma-type granites of Vallance (1969). Six kilometers east of the Lockhart Granite is the areally large and massive Koetong Granite, which is continuous (Guy, 1969) with the Corryong-Maragle Granites, forming a single granite mass some 100 kilometers in length. The Koetong Granite is overprinted by a \( D_{NW} \) fault in the Walwa area, and in places possesses a weak flow foliation trending \( 150^\circ \). Chemical data show that these latter granites are different chemically from the Lockhart, Albury, Cooma and Omeo Granites (Fig. 3), but as yet no data relating the relative intrusion times of these two granite types have been uncovered. White et al. (1974) contended that the whole of the Koetong-Corryong-Maragle mass is a contact aureole granite. The apparent change in grade from biotite zone to sillimanite zone rocks in less than 1.5 kilometers in schists bordering the Koetong Granite suggests a geothermal gradient far steeper than that implied by the metamorphic zonation at Cooma, Albury or the Kiewa Valley area. Arndt (1969), Singer (1974) and Smart (1975) demonstrated that contact metamorphism is quite widespread around parts of the Koetong-Corryong Batholith.

Several leucogranites, including the Pine Mountain Granite

\[ \text{CaO} \]
\[ \text{Na}_2\text{O+K}_2\text{O} \]
\[ \text{MgO+FeO+MnO} \]

**FIGURE 3**


and the Mount Mittamatite Granite, intrude the Koetong-Corryong Batholith. Brooks and Leggo (1972) and Kolbe and Taylor (1966) summarised the essential features of these granites which are similar to leucogranites that are part of the Murrumbidgee Batholith (Snelling, 1960; Joyce, 1973). Small contact aureoles are present around the former bodies. East of Mitta Mitta, a hornblende-bearing granodiorite, the Bannimboola Granodiorite, crops out on the western flank of Mount Benambra. In road cuttings in this area, the granodiorite boundary is seen to be dipping shallowly outwards from the centre of the mass, and a contact aureole having an outcrop width of six kilometers is developed in low-grade regional metasediments to the west and south of the granodiorite. This granodiorite has most of the features of the Bathurst-type granites of Vallance (1969).

Over geological time a distinct pattern in the distribution of the isotopes of sulphur has resulted from the combined effects of a variety of natural processes. The processes which lead to this isotopic fractionation are becoming increasingly understood and accordingly offer wider opportunities for the application of isotopic measurement to geological problems.

Sulphides from a number of localities in the Lachlan Fold Belt are being investigated as part of a wider study. The expectations are that these measurements might eventually reveal mineralization patterns, sources of sulphur, centres of volcanic activity and directions of flow of mineralizing solutions. It is yet too early to attempt the interpretation of the very limited data in all these directions, but the preliminary isotopic data for sulphides from the Lachlan Fold Belt, selected where possible from main ore bearing horizons (Fig.1), reveal a considerable range of $\delta^{34}S$ values.

Although the genesis of ores of the Kuroko type sulphide deposits is still subject to some doubt, it is generally agreed that seawater sulphate, either coeval or fossil, is the principal sulphur source in a submarine, hydrothermal process operating at a temperature of 250-300°C. Typical metal sulphide and sulphur isotope distribution patterns have been described with $^{34}S$ contents decreasing from +100/oo and +80/oo in underlying pyritic veins through values of +60/oo to +30/oo in the ore zone. In the uppermost layers where contact with Miocene ocean water occurred, barites with $\delta^{34}S$ values of +220/oo to +230/oo are found.

Sulphides from deposits at Woodlawn and Colo Creek have distributions and isotopic compositions which generally correspond closely with the Kuroko values and which also suggest equilibration temperatures approaching 300°C.

Only in respect of the $^{34}S$ contents of the barites is there a significant difference. Those from the Lachlan Fold Belt appear to be more enriched in the heavier isotope, a difference in composition which correlates well with the increased $^{34}S$ content of the ocean sulphate during the Silurian.

A similar isotopic relationship, indicating the same equilibration temperature (250-300°C), also exists between the sulphides from Mount Bulga and Currarong, although all samples are depleted in the heavier sulphur isotope. Similarly depleted are the three remaining sulphide deposits of similar age, that is those at Copper Hill, Lime Kilns and Basin Creek, but, since only chalcopyrite and pyrite were examined or were present in these, comparisons with other sulphides become less meaningful.

Thus, whilst isotopic fractionations between sulphides from the same deposit all seem to be in general accord, quite marked differences in the $^{34}S$ contents of sulphides from different deposits are seen. Two alternative explanations for this latter effect are either that varying $^{34}S$ contents reflect the relative contribution of sulphur from volcanic and ocean water sources, or that the sulphur source and reservoir remain unchanged and decreasing $^{34}S$ values in the sulphides reflect increases in pH or oxygen fugacity.

Interest in the Devonian samples from E. Gippsland centres largely on the associated barite. The isotopic composition of this as given in Fig. 1 is in accord with the values generally accepted for Devonian ocean sulphate.

MINERALIZATION OF THE LUCKY HIT COPPER MINE, MERRILLA MINE AND GURRUNDA BARITE DEPOSIT, NEW SOUTH WALES

F.I. Roberts
Geology Department,
University of Wollongong,
PO Box 1144, Wollongong, NSW 2500

B. Mutton
Mt Isa Mines Ltd.
Mount Isa, Qld. 4825

See Programme and Abstract Volume of Conference.

ANTIMONY MINERALIZATION IN VICTORIA – A CASE FOR REGIONAL ZONING?

M. Hill
Geological Survey of Victoria,
107 Russell Street, Melbourne, Vic. 3000

See Programme and Abstract Volume of Conference.

6. SPECIALIST STUDIES

$^{34}S/^{32}S$ RATIOS IN SOME SULPHIDES OF THE LACHLAN FOLD BELT

M.S. Burns and J.W. Smith
CSIRO Division of Mineralogy,
PO Box 136, North Ryde, NSW 2113