Fe^{2+}, Zn, Mn, Ni, Co, or other divalent ions are present, but there is no reason why a similar type of result might not be found in other systems. An example of a system in which this method may prove useful is the steelmaker's high-fired chrome-periclase refractory, in which the resulting spinel after service is essentially a complex Mg spinel; any original FeO has been oxidized and combined with free MgO to form additional "$MgFe_2O_4$" molecule.

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THE ORIGIN OF MECHANICAL TWINNING IN GALENA

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In the course of a general investigation into the plastic properties of galena (Lyall and Paterson, 1965) it was found that mechanical twinning with composition plane (441) could be produced in single crystals tested in compression at room temperature and at 2.5 and 5 kilobars confining pressure, provided the crystals had an initial length to cross-section area ratio less than 0.7 and were oriented so that the resolved shear stress on {001} ⟨110⟩ slip systems was initially zero; otherwise {001} ⟨110⟩ slip occurred. Both the general appearance and annealing behavior of these experimentally produced twins are quite distinct from that of (441) lamellar twins which occur in large single crystal blocks of galena from Broken Hill, New South Wales. The latter (Fig. 1a) are commonly 10 to 50 μ thick, discontinuous and never intersect; they anneal by blunting (Cahn, 1954) and absorption by the parent crystal (Fig. 1b). The experimentally produced twins (Fig. 1c) are invariably thicker by an order of magnitude or more, form highly strained junctions and anneal by recrystallization and grain growth within the twin volume (Fig. 1d).

Consideration of the effects of high temperature and high pressure on mechanical twinning in minerals (Cahn, 1954) and the effects of shock loading and high strain rates on mechanical twinning in metals (Rinehart and Pearson, 1954; Zukas and Fowler, 1961) suggested that the (441) lamellar twins in the Broken Hill crystals might have been pro-

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duced by blasting during mining operations. This hypothesis has been checked by impact tests on macroscopically underformed galena crystals normal to {001} cleavage faces. The crystals were embedded in paraffin wax and placed in the bottom of a brass die into which a closely fitting steel piston was projected at high velocity (Fig. 2). This was done by firing a blunt bolt from a Ramset Fastening Gun to strike the top end of

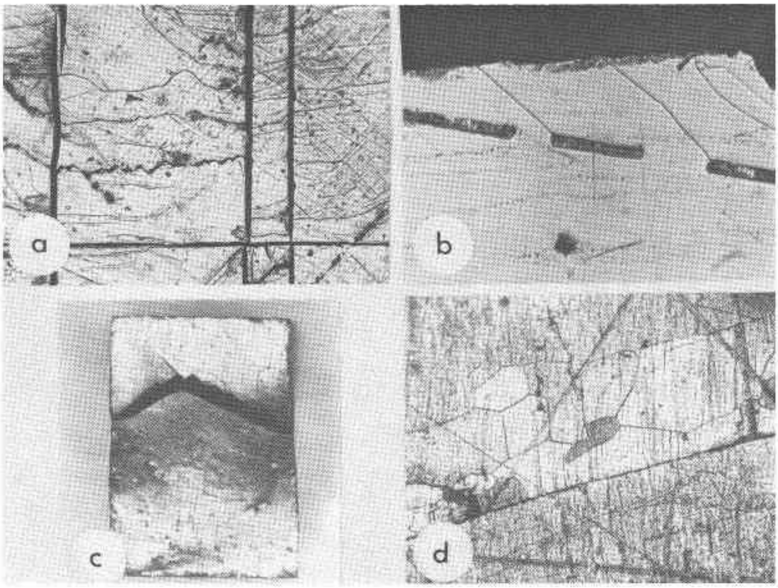

FIG. 1. (a) Lamellar (441) and (4$\bar{4}$1) twinning on a (001) cleavage face of a galena crystal from Broken Hill; the faint conjugate traces on the upper half of the photograph are slip lines produced during cleavage; ×200. (b) Absorption of (441) lamellar twin observed on a (010) face after heating for 4 hours at 600° C.; ×300. (c) (441) mechanical twinning produced in compression at 5 kilobars confining pressure; ×10. (d) Recrystallization within the twin volume of an experimentally produced (441) twin after heating for 8 hours at 600° C.; ×200.

the piston. The strain rate was probably of the order of several powers of ten per second and on the basis of the wax extrusion around the piston after impact, it was estimated that the confining pressure on the crystals at impact was of the order of several kilobars.

The experimental results obtained for 16 crystals were as follows: 7 fractured on {001} cleavage faces perpendicular and parallel to the axis of impact; 7 deformed by (441) twinning and 2 by a combination of twinning and kinking. In the 7 crystals not containing kinks, (441) lamellar twins up to 50μ thick were observed near the tops of 5 crystals; these twins annealed by blunting and absorption by the parent crystal; the bulk of each crystal was occupied by junction-forming twins up to 200 μ thick whose annealing behaviour was identical to that described for (441) twins produced in compression at high confining pressure. In the kinked specimens (Figs. 3a and b), only the latter type of twin was observed.

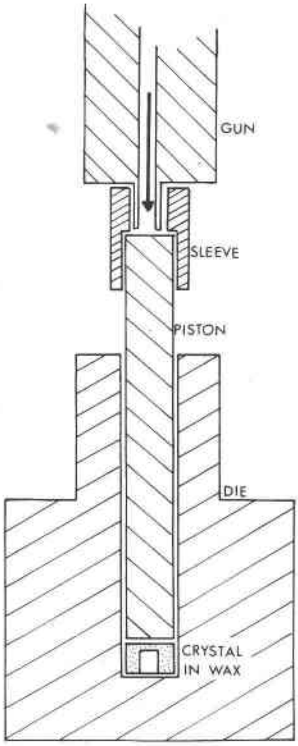

FIG. 2. Sketch in section of the apparatus used in the impact experiments.

The kinking in the impact tested crystals, which involves slip on only one set of {001} planes, is quite distinct from that observed

(i) in single crystals oriented so that two sets of {001} ⟨110⟩ slip systems are initially equally stressed and in galena aggregates, all tested in compression at room temperature and high confining pressure (Lyall and Paterson, 1965);

(ii) in a deformed crystal from a known fault zone (Fig. 4).

In the single crystals and in aggregates deformed in compression, the kinking (Fig. 3c and d) involves initial {001} ⟨110⟩ double slip and is considered to be a response to specific constraint conditions rather than a general deformation mechanism contributing significantly to the short-

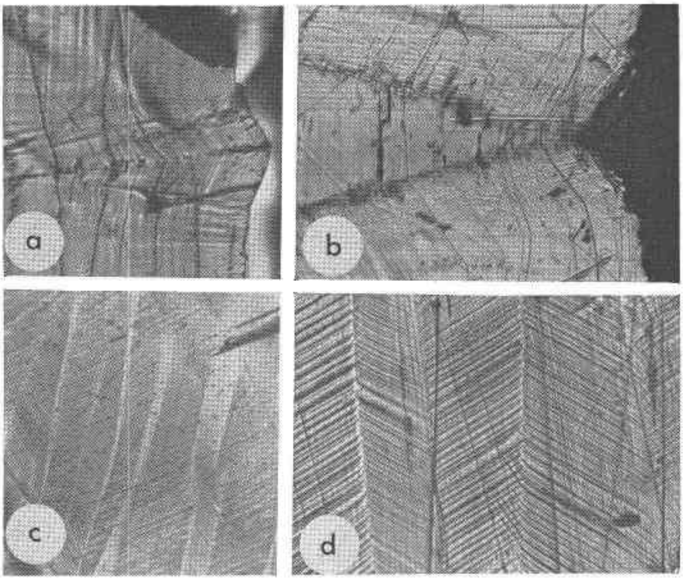

FIG. 3. (a) and (b) kinking produced in galena single crystals tested under impact normal to {001}; the dark band in (a) is a (441) twin of junction-forming type; ×70. (c) Kinking in polycrystalline galena strained 7% in compression at 5 kilobars confining pressure; ×200. (d) Kinking in a galena single crystal oriented so that two {001} ⟨110⟩ slip systems were initially equally stressed; ×350.

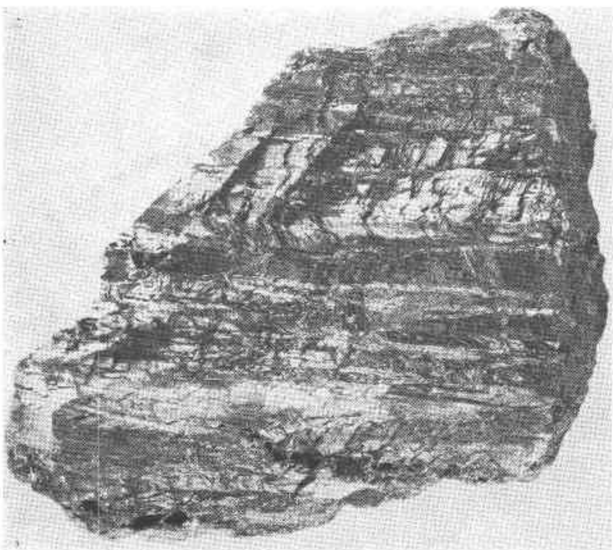

FIG. 4. Kinking in a deformed single crystal from the Zeehan fault zone, Tasmania; ×1½.

ening of the specimens. In the naturally deformed crystal, the repeated kinking with sub-parallel kink band boundaries may be identical to that observed in the single crystals and aggregates deformed in compression.

Mechanical twinning has so far not been observed in polycrystalline galena (0.1 to 0.5 mm grain-size) deformed up to 14% in compression at room temperature and high confining pressure. Although high temperature as well as high pressure sometimes facilitates twinning (Cahn, 1954), on the evidence of the impact experiments and the special conditions required for twinning in single crystals at high pressure, it seems likely that the suggested blasting origin for "natural" (441) lamellar twins is a reasonable one and that in addition, (441) twinning is unlikely as an important deformation mechanism at slow strain rates in the earth's crust. However, kinking and slip on systems other than $\{001\}\ \langle 110 \rangle$, probably $\{110\}\ \langle \bar{1}10 \rangle$ (Lyall and Paterson, 1965), may become increasingly important in nature.

Acknowledgements

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