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The Formation of Extrinsic-Intrinsic Faulting

by

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ABSTRACT

Formation mechanisms for extrinsic-intrinsic node pairs and fault pairs are presented. Extrinsic faulting can arise from the intersection of dislocations whose long range force is either attractive or repulsive. Micrographs support the proposed mechanisms, and it appears likely that the extrinsic faulting arises directly, during the intersection, or subsequently, as the result of further forces applied to an intrinsically faulted configuration.

1. INTRODUCTION

Whelan (1959) considered a number of the possible configurations arising from the interaction of dislocations lying on intersecting slip planes. Hirth (1961) considered the problem further, and allowed for the possibility of the formation of extrinsic faulting, although he, like Whelan earlier, thought that such faults were unlikely to form. Recent work, however, has established that extrinsic faulting can be readily observed in low stacking fault energy (γ) materials (Loretto, 1964; Ives and Ruff, 1966; Gallagher, 1966) and also in relatively high γ materials including pure silver (Gallagher and Washburn, 1966). This is not unreasonable since it has recently been established that the extrinsic and intrinsic stacking fault energies (γ_e and γ_i respectively) are closely equal (Gallagher, 1966).

In the present work formation mechanisms of extrinsically faulted configurations are presented and illustrated by electron micrographs of various silver-base alloys. It appears likely that node pairs and extrinsic-intrinsic "fault pairs" (Gallagher, 1966) can be formed either directly as a result of an intersection, or as a second step following the formation of an intrinsically faulted network of extended and contracted nodes.

2. DIRECT FORMATION OF EXTRINSIC-INTRINSIC FAULTS

In considering the reactions of intersecting dislocations in f.c.c. materials the notation of Thompson (1954) will be used. In Fig. 1a), b) we consider the intersection and interaction of two attractive dislocations, for which the smaller the angle β the greater the attraction. The preliminary stage of the interaction is the formation of a constriction as in Fig. 1a). In the case illustrated cross-slip will occur and the dislocation $\delta CB\delta$ will become extended in the α plane enabling the lengths of the partials $C\alpha$ to be reduced. As the partials $C\alpha$ move away from the constriction extended nodes are formed in the α plane; in one case the fault is extrinsic, in the other, intrinsic. Locally, the resultant configuration illustrated in Fig. 1b) has reduced the number of partial dislocations from 4 to 2 with a consequent saving in energy. It is clear from Fig. 1b) that the line joining the constriction points X,X' should correspond to a $\langle 110 \rangle$ direction. In cases for which the position of the point X' may be determined this has been found to be the case. Frequently, however, the dislocation CB emerging from the intrinsically faulted node remains extended in the α plane (the dislocation having cross-slipped along its entire length), and the constriction X' does not form.

As the angle β in Fig. 1a) increases towards 90° the resultant configuration of Fig. 1b) is somewhat modified. The lengths of the dislocations αA and αB can be reduced, as also can the elastic interaction energy, by the formation of a cross-linking dislocation of Burgers vector αC in place of the constriction at Y. Such a configuration has been described in a number of the references cited earlier, and will be illustrated below.

For an angle $\beta \gg 90^{\circ}$ the long range dislocation interaction is repulsive. However, when the short range interaction between the individual partials is considered the situation is one of weak attraction. In Fig. 2a) as in the earlier figure, the dislocation CB is extended on the β plane, and a constriction has formed at the intersection with $\alpha AC\alpha$. A stress concentration, for example at the head of a pile-up, is probably necessary for this reaction to occur.

Once again, cross-slip of one dislocation, $\delta CB\delta$, enables the lengths of the partials $C\alpha$ to be reduced, while in addition segments of $A\alpha$ and $B\alpha$

combine to produce a resultant dislocation, $C\alpha$, the reactions zipping outwards from the original constriction. The smaller the angle between the intersecting dislocations (i.e. the closer is β to 180°), the greater will be the length of the fault pair. Locally the number of partials is reduced from 4 to 3, once again the direction XX' will be $<110>$, and the fault pair lies wholly in one plane. The configuration, while co-planar in this sense, involves the superposition of $A\alpha$ and $B\alpha$ on an adjacent pair of α-type planes to produce the central partial $C\alpha$, as described earlier (Gallagher, 1966; Fig. 13).

Thus, extrinsic-intrinsic fault configurations can form for any value of β during the intersection of dislocations which can cross-slip. With increasing β the type of configuration changes smoothly from a node pair through a cross-linked node pair to a fault pair. It has already been pointed out (Gallagher, 1966) that the latter configuration provides a most advantageous means of determining both the extrinsic and intrinsic stacking fault energies, and also served to show that γ_e and γ_i are closely equal. The simplicity of the configuration makes it possible to apply anisotropic elasticity fully in a determination of the stacking fault energy, and this has recently been accomplished (Teutonico, 1966).

Node pairs, both with a central constriction, and cross-linked are shown in Fig. 3, in which the arrows indicate traces of $<110>$ directions. The constrictions X and X' are particularly clear in the node pair of Fig. 3a). The cross-linked node pair of Fig. 3b) is rather unusual in that the extrinsically faulted area is larger than the intrinsic. In this case, too, the constrictions X and X' can be distinguished, a stereo pair of pictures having aided the identification. Fig. 3c) shows a more usual node pair in which the intrinsically faulted area is larger than the extrinsic. In Fig. 3d) the dislocations emerging from the fault pairs have cross-slipped along their entire lengths, and the constrictions X' have consequently passed out of the foil. For the cross-linked node pair in Fig. 3d), however, both constrictions are readily visible, while the positions at which the emerging dislocations intersect the foil surface make it clear that they have changed planes.

3. FORMATION FROM A NETWORK OF EXTENDED AND CONTRACTED NODES

Whelan (1959) showed examples of intrinsically faulted extended and contracted nodes in networks in stainless steel. Such networks are frequently observed in relatively low γ materials, and arise from the intersection and interaction of several dislocations. Normally, one or more dislocations of Burgers vector $\underline{b}_1$ emitted from a source on one plane interact with one or more dislocations with $\underline{b}_2$ emitted on another plane, and, following cross-slip, as described by Whelan (1959), the network of nodes is formed in one plane.

An example of the complicated configurations which can arise when the network contains both extrinsic and intrinsic faulting is afforded by Fig. 4. The micrograph Fig. 4a) is of an area which was examined with three different reflections enabling the complete Burgers vector assignment, Fig. 4b), to be made. A number of the configurations shown in Figs. 1 and 2 are readily recognizable, and further confirmation of the presence of extrinsic and intrinsic faulting is visible in the offset of stacking fault fringes in many regions where extrinsic and intrinsic faults abut. Care must be taken in making the Burgers vector assignment to allow for the contrast anomalies which occur when a Shockley partial separates extrinsic from intrinsic faulting (Gallagher et al., 1966).

This complicated configuration is the result of interactions by 7 dislocations of $\underline{b_1} = 1/2[101] = 1/6[112] + 1/6[2\bar{1}\bar{1}]$, with 3 dislocations of $\underline{b_2} = 1/2[1\bar{1}0] = 1/6[2\bar{1}\bar{1}] + 1/6[1\bar{2}\bar{1}]$. The tortuous path of some of the dislocations with $\underline{b_1}$ may readily be traced, while the three dislocations with $\underline{b_2}$ lie more uniformly from left to right.

It may well be that configurations such as these form as a result of the application of stress to a regular network of intrinsically extended and contracted nodes. Figure 5 illustrates how this may occur. Stress is applied to the intrinsically faulted network of Fig. 5a), causing one of the three types of partial to move towards the obstacle. The other two types of partial feel a much smaller force, so the movement leads to the formation of extrinsic-intrinsic node pairs. In the regions of higher stress concentration at the head of the pile-up of moving partials, the angle β becomes sufficiently large for a cross-linking dislocation to form in the node pairs. Thus, for a moderate applied stress the configuration of Fig. 5b) is to be expected.

On increasing the stress further β becomes large enough to permit a greater amount of dislocation zipping to occur, leading to a final configuration such as Fig. 5c). For the sake of simplicity in Fig. 5, cross-linking dislocations have been drawn only at constrictions of type B, E, F, H, J (in Fig. 5b), i.e. for the reaction which is <u>most</u> stress-aided. A typical example of a pile-up against a sub-grain boundary is shown in Fig. 6, and whilst the general features of the diagram Fig. 5c) are clearly present, one may readily discern that cross-linking dislocations of two different Burgers vectors have formed, the one leading to a line of no contrast between extrinsic and intrinsic faults (e.g. at A,B,C), the other to strong contrast (e.g. at D,E).

A final example of the formation of extrinsic faulting is shown in Fig. 7. It serves to show that even an isolated node may be changed into a fault pair, in this case as the result of a change in local stress due to the movement of another dislocation. The interaction leads to a substantial increase in angle β, enabling the fault pair to form (Fig. 7b). Fig. 7c) illustrates that (at 150° C) extrinsic-intrinsic fault configurations of this nature are glissile.

CONCLUSIONS

1. Isolated extrinsic-intrinsic node pairs and fault pairs can be formed directly as the result of the intersection of dislocations whose long range interaction is either attractive or repulsive.

2. Following the formation of an intrinsically faulted configuration modifications in the local forces can cause a change to an extrinsic-intrinsic configuration, a process which appears likely in a faulted network.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1, a) Dislocations with long range attractive force form a constriction, and b) reduce their total energy by forming an extrinsic-intrinsic node pair in the α plane.

Figure 2, a) Dislocations with long range repulsive force form a constriction with the aid of stress, and b) reduce their total energy by forming an extrinsic-intrinsic fault pair in the α plane.

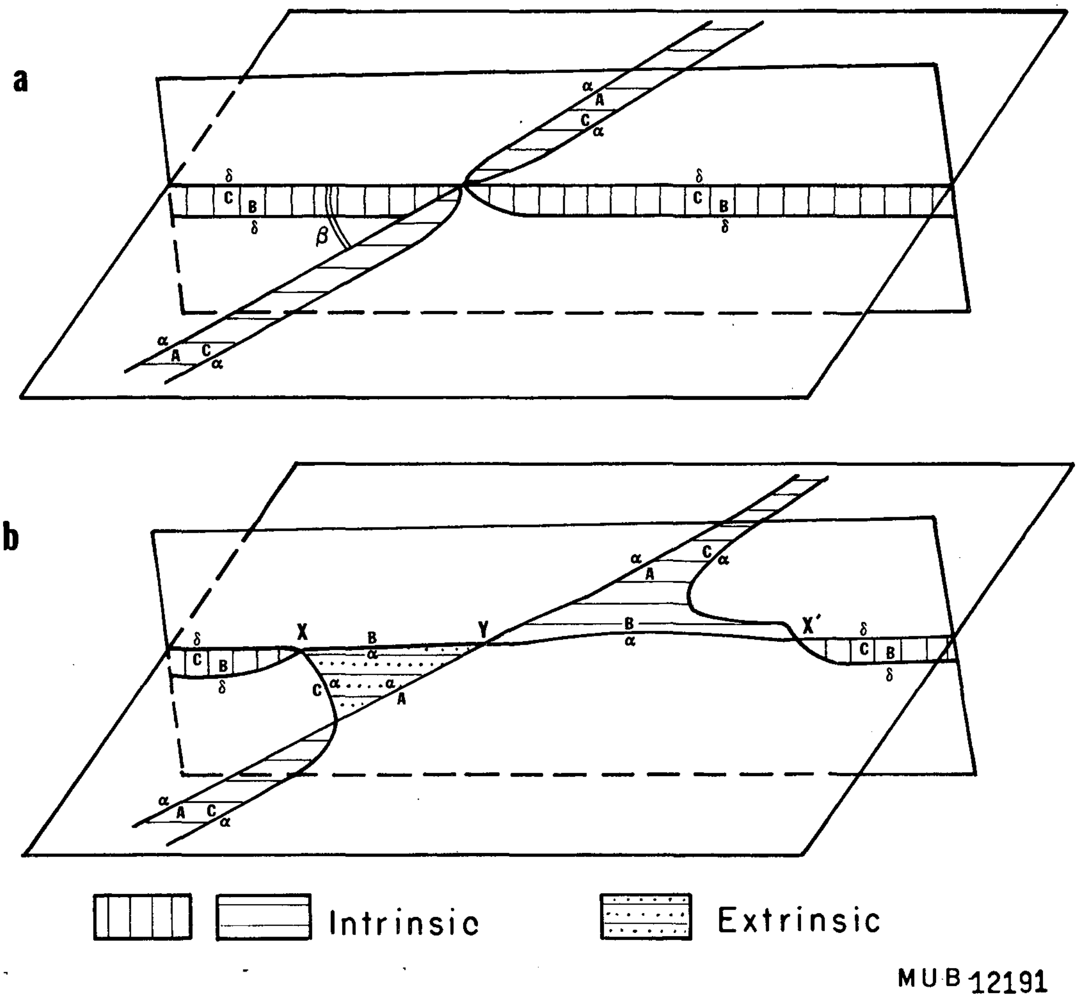
Figure 3, a) Node pair in Ag-In alloy, with e/a = 1.23, b) cross-linked node pair in Ag-In alloy, with e/a = 1.15, c) cross-linked node pair in Ag-In alloy, with e/a = 1.23, d) fault pairs and cross-linked node pair in Ag-In alloy, with e/a = 1.15. The arrows denote <110> traces.

Figure 4, a) Complex extrinsic-intrinsic network, in Ag-In alloy, with e/a = 1.23, b) Burgers vector analysis of same.

Figure 5, a) Intrinsically extended and contracted nodes, b) application of stress leads to the formation of extrinsic faulting, c) possible final configuration.

Figure 6, Typical extrinsic-intrinsic faulting in pile up against boundary, Ag-In, e/a = 1.23.

Figure 7, a) An intrinsic node in Ag-In, with e/a = 1.23, at 150° C, b) a moving dislocation causes an extrinsic-intrinsic fault pair to form, c) the fault pair glides in the foil.


a
α
A
C
α
δ
C
B
δ
β
δ
C
B
δ
α
A
C
α
b
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A
C
α
X
B
α
Y
B
α
X′
δ
C
B
δ
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C
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Intrinsic
Extrinsic
MUB 12191

Fig. 1

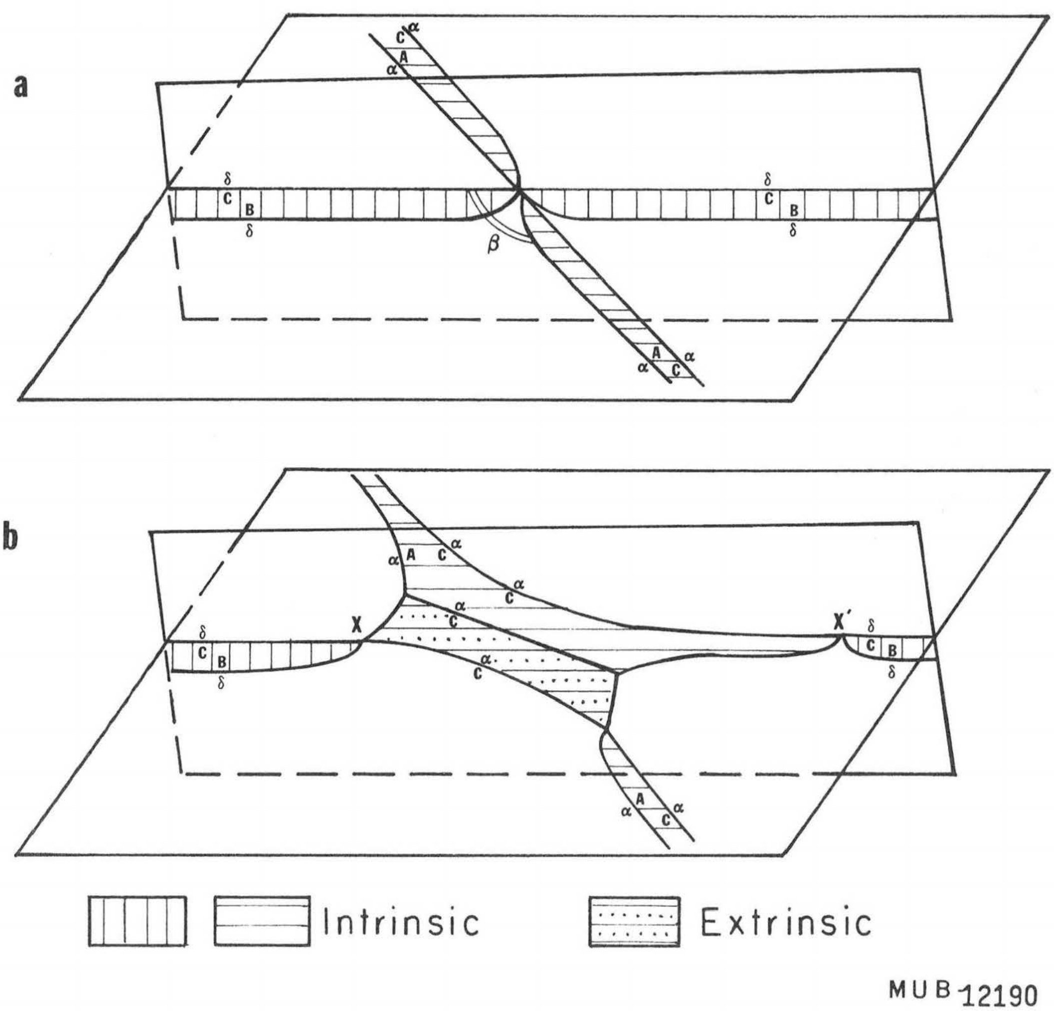

Fig. 2

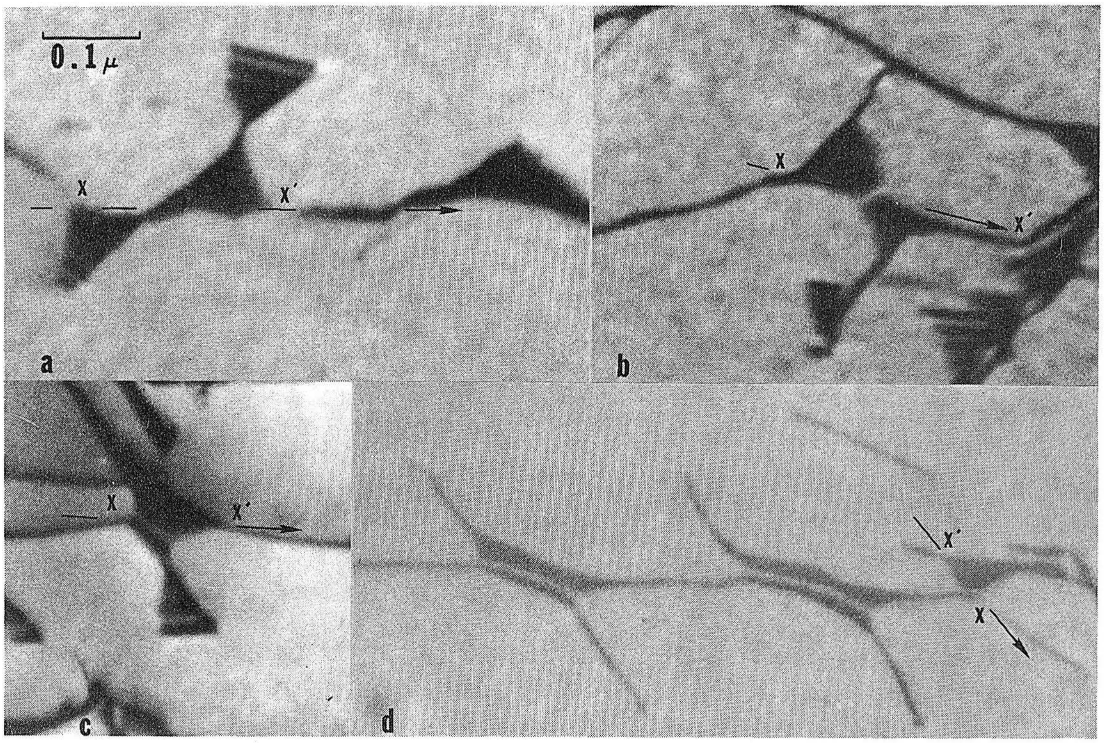

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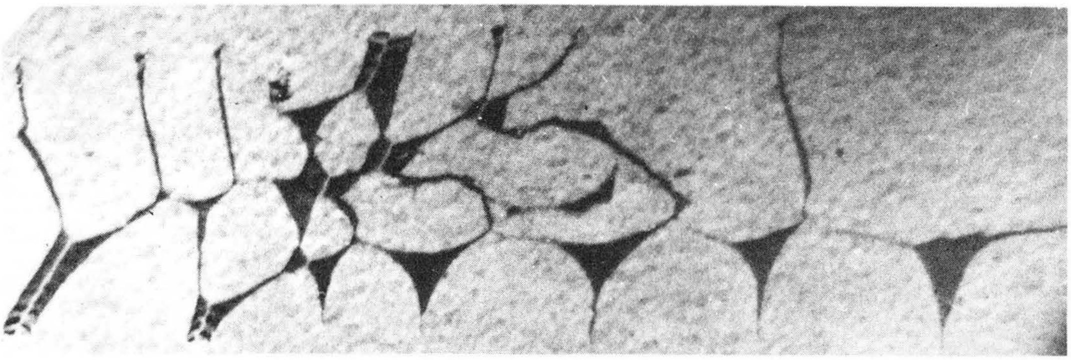
Fig. 3

a



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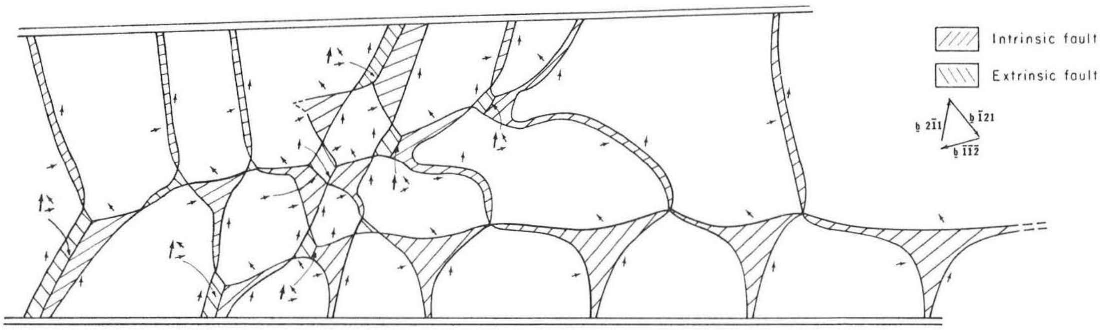

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Fig. 4

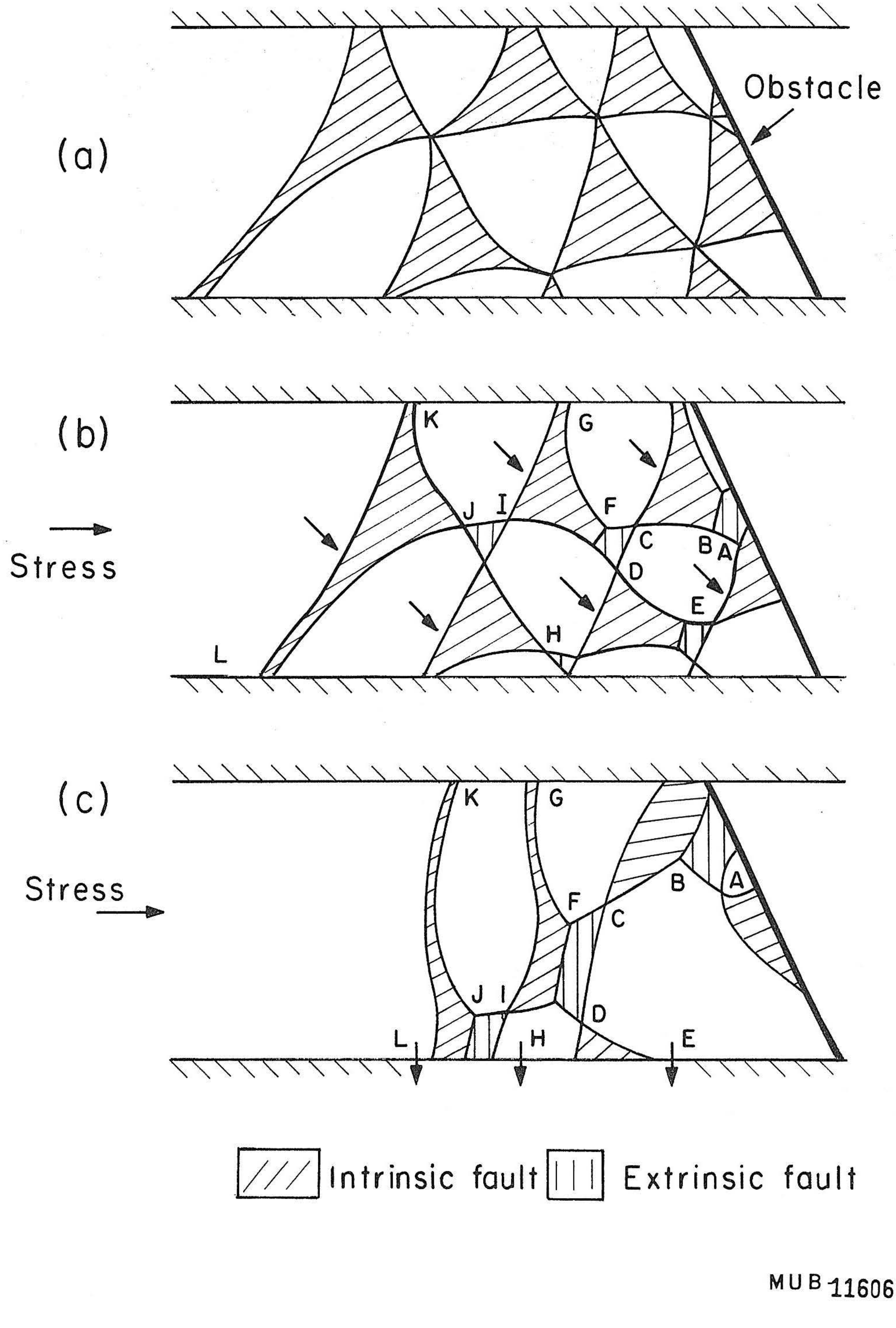
(a)
Obstacle
(b)
Stress
K
G
J
I
F
C
B
A
D
E
H
L
(c)
Stress
K
G
F
C
B
A
J
I
D
L
H
E
Intrinsic fault
Extrinsic fault
MUB 11606

Fig. 5

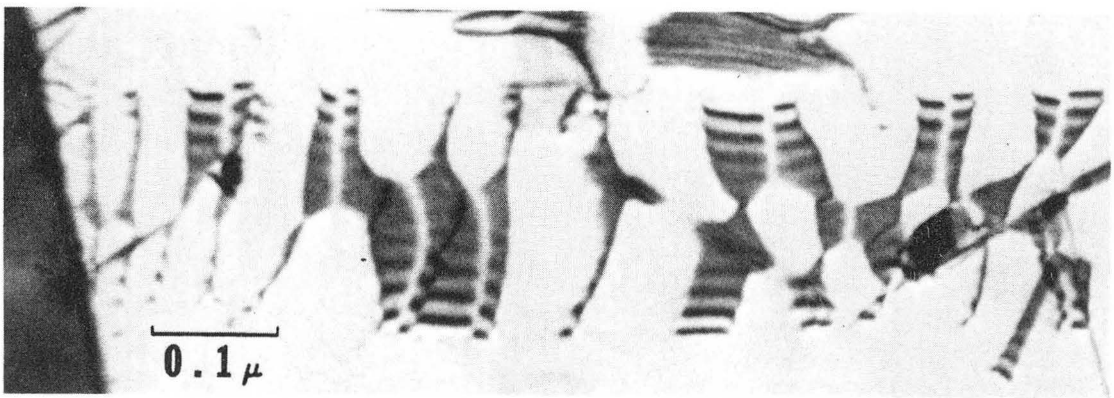

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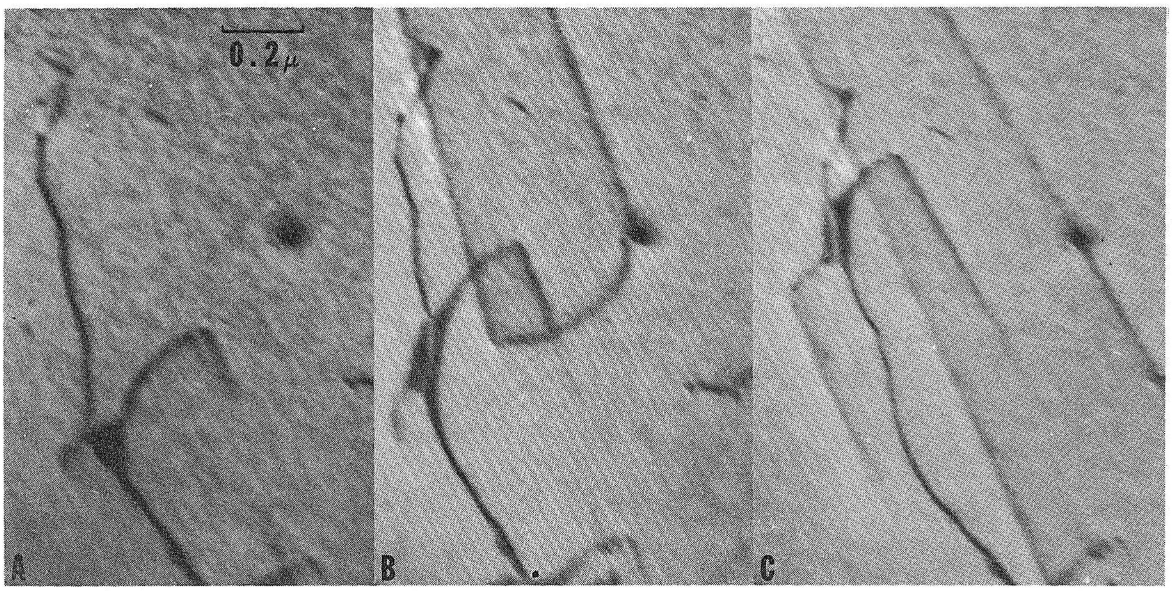
Fig. 6



ZN-5887

Fig. 7