ON WHOLENESS AND THE IMPLICATE ORDER IN CRYSTALS AND ITS IMPLICATIONS FOR CONSCIOUSNESS STUDIES[1]

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ABSTRACT: This paper is a collection of analogies on wholeness and the implicate order drawn from the field of materials science and engineering. The study of the polycrystalline materials has many applicable analogies in terms of understanding of wholeness, the implicate and explicate orders in consciousness studies. The author presents an analogy that describes the notion of wholeness in the context of behavior of a polycrystal under a uniaxial compressive load. A second analogy describes the notions of implicate and explicate orders in the context of a single, compressed crystal of magnesium examined in a scanning electron microscope (SEM). The theories, experimental techniques and computational methods associated with each analogy are presented in a non-technical framework. A number of implications for consciousness studies are presented. Through the development and presentation of analogies in a science and engineering field, the author attempts in providing certain immediate perceptual insights into what is meant by wholeness as well as implicate and explicate orders, as the new paradigm in consciousness studies.

KEYWORDS: Wholeness; Implicate order; Consciousness

> "All mediums have their limitations as to what they can inscribe and describe, and modulating within these perimeters is all we can rationally ask of any practitioner."
>
> Robert Polidori, Points Between…Up Till Now [1]

[1] Note: This manuscript is based on the original oral presentation at the Foundations of Mind Conference III, held May 18-20, 2016 in University of California, Berkeley. The discussions presented have not been previously published elsewhere; nevertheless, the analogies drawn from the field of materials science and engineering are highly based on the articles previously published in scientific journals by the author and may include inevitable duplications from previous works.

INTRODUCTION

Wholeness and the implicate order is a model of reality (in general) and consciousness (in particular) which was first proposed by David Bohm in 1980 [2]. This model describes a world view in which reality and consciousness are related to each other in an overall whole that is undivided, unbroken and without borders. Two notions of order appropriate to such unbroken wholeness were introduced, namely the implicate order and the explicate order. The *implicate* or *enfolded* order is primary, independently existent and universal order which is contained implicitly in each region of space and time. The e*xplicate* or *unfolded* order flows out of a law of implicate order and therefore, it is secondary, derivative and appropriate only in limited contexts of space and time [2].

Bohm presented the hologram and ink in fluid stirring device analogies to provide perceptual insights into the meanings of wholeness, implicate and explicate order of his model. The function of the hologram was used to characterize the notions of wholeness and implicate order, showing that each region of a photographic plate contains within it the whole three-dimensional structure and each region of the structure is relevant to the whole of the interference pattern on the plate. The ink in fluid stirring device was used to demonstrate processes in which the explicate order becomes relevant, noting that the parts of the ink droplets remain in a one-to-one correspondence as they are stirred up in a continuously moving fluid [2]. The force applied to the fluid through the mechanical rotator is not conditioned by the ink droplet as a whole or the parts of the thread of ink. The force is beyond the whole and the parts and yet, drives the system to go from the implicate domain of droplet to the explicate domain of a thread of ink and vice versa. This force is an inherent in the overall system. At a deeper level, it has its own set of implicate and explicate orders and correspondingly a deeper force that would drive their transformation into each other as discussed in sub-system, system and super-system theory in [2]. Together with F. David Peat, Bohm presented further examples of implicate order in the fields of art, poetry and music to emphasize a broad significance of the implicate order, not only in science but in the overall order of society and individual human beings [3].

In this paper, the wholeness, implicate and explicate order are further explored with the help of a number of analogies drawn from the field of materials science and engineering. The main objective of this paper is to use the theories, experimental techniques and computational methods already developed and validated in materials science and engineering to support and further discuss the wholeness and the implicate order model in consciousness studies [2].

The content of this paper is organized in three sections. The first two sections present two analogies drawn from the fields of crystals plasticity and electron microscopy, respectively. For each analogy, the relevance to the wholeness and the implicate order model [2] is described. The implications for consciousness studies are discussed in the third section. The paper concludes with a proposal to the community of consciousness researchers to bring about the well-developed and well-established theories, techniques and methods from hard sciences in exploration, examination and mapping the nature of reality and consciousness as *one* undivided whole.

ANALOGY I. WHOLENESS OF A POLYCRYSTAL

> "When at last we shall rush rapidly past objectness we shall probably see the totality of the whole world."
>
> Mikhail Matyushin [4]

In this section, the wholeness of a polycrystal is presented as an analogy of the wholeness of reality and consciousness in Bohm's model [2]. A polycrystal is a solid aggregate of crystals of varying crystal orientation and size. Figure 1 shows a schematic of a polycrystal with three examples of individual crystals indicated with *A*, *B* and *C*. Each crystal contains crystal planes (shown with parallel lines) of certain orientation in the volume of the aggregate. If the aggregate is subjected to a uniaxial compressive load shown with top and bottom arrows in Figure 1, the aggregate and its constituent crystals change shape. The stress S of aggregate is indicated with $S_{Aggregate}$ and the stress in individual crystals *A*, *B*, *C* is indicated with S_A, S_B and S_C, respectively. Each crystal experiences a fraction of the overall load, depending on its position and crystal orientation in the volume of aggregate. Therefore, the stress of aggregate differs from the stress in individual crystals ($S_A \neq S_B \neq S_C \neq S_{Aggregate}$). As a result, the behavior of aggregate is not simply deduced by averaging the behavior of individual crystals.

Upon compression, the shape change of each crystal does not occur freely, but is dependent on simultaneous shape change of adjacent crystals surrounding it. This indicates that the behavior of each crystal depends on the behavior of the rest of the aggregate and vice-versa. In addition, the interactions between adjacent crystals and interactions of each crystal in relation to the aggregate are constantly changing the behavior of aggregate and constituent crystals during compression.

Materials scientists use *self-consistent models* [5] in order to successfully predict the numerical results of a uniaxial compression experiment on a polycrystal. Self-consistent models are based on *the science of muddling through* [6]. This approach is based on construction of a preliminary solution from the initial situation and building out the solution in a step-by-step process with successive limited comparisons. The final solution is achieved through adaption and iteration, with constant rebalancing of incompatible and incommensurable components that are imperfectly known but acquired as the process goes on [7].

The results of self-consistent models show that each crystal not only represents the aggregate but also contributes to it [8,9]. The aggregate and its constituent crystals act according to a general relationship [10] which can be regarded as a *stress flux* transferring the overall load of aggregate at macroscale to each crystal at microscale and vice versa. The aggregate and its constituent crystals change shape in relation to this flux such that the whole entity is self-consistent at all length scales. The constant enfoldment-unfoldment processes of crystals going into shape change, orientation change and phase transitions take place when the crystal is subjected to an external force analogous to the force in the ink in fluid stirring device analogy [2].

The behavior of a polycrystal under a uniaxial compressive load offers a striking resemblance to the behavior of plasma which was the subject of study of Bohm [11]. He perceived the behavior of plasma as a highly organized system which behaves as a whole and acts similar to a living being. Bohm worked with self-consistent mathematical formalism, a similar approach of materials scientists in using self-consistent models, which correctly predicted the numerical results of the plasma experiments [11]. In the framework of wholeness and implicate order model, the polycrystalline aggregate is considered as one undivided whole and the constituent crystals are considered its parts. Each part behaves as an individual component, but as part of a larger, undivided whole.

ANALOGY II. IMPLICATE AND EXPLICATE ORDERS IN ELECTRON MICROSCOPY

> "By putting things in order, I create and understand at the same time."
>
> Clarice Lispector, The Passion According to G.H. [12]

In this section, the notions of implicate and explicate orders in Bohm's model [2] are further explained in the context of electron microscopy. A scanning electron microscope (SEM) uses an electron beam to illuminate and magnify the surface of a specimen for observation and analysis [13]. Figure 2 shows a schematic of crystal *A* from the polycrystal in Figure 1 under the electron beam. The near surface crystal planes rotated about a rotation axis inside the crystal. The red crystal planes indicate the positions where the Bragg's law of electron diffraction (with Bragg angle θ_B) is satisfied [13]. The rotation of crystal planes is attributed to the shape change of crystal under the uniaxial compressive load (shown in Figure 1).

If this crystal is examined in SEM, the near surface, three dimensional volume of the crystal is projected onto a two dimensional image using the imaging and diffraction techniques. Figure 3 shows the schematics of crystal-detector configurations for imaging and diffraction techniques in SEM, respectively. The green shaded areas indicate the electrons scattered and detected by the detector to form an image. A description of each technique is beyond the scope of this paper and the detailed information can be found in [14].

Figure 4 shows the results for a compressed crystal of magnesium examined in SEM. Figure 4a shows a schematic image in a Cartesian (x-y) space with a band of contrast across a dark gray background. The band is aligned parallel to the rotation axis of the compressed crystal and the edges of the band correspond to the positions where the Bragg's law of electron diffraction is satisfied. Therefore, there is one-to-one correspondence between the three dimensional volume of the crystal being scanned and the two dimensional image formed by the detector [15]. For example, subset I in Figure 2 corresponds to subset I in Figure 4a. Figure 4b shows a diffraction pattern formed in an angular space (ψ-φ). This pattern contains bands and lines representing different sets of crystal planes in a crystal. Each region of the pattern contains within it the three dimensional structure of the crystal and each region of crystal is relevant to the whole of the pattern. Therefore, there is *no* one-to-one correspondence between the three dimensional volume of the crystal being scanned and the two dimensional pattern formed by the detector [16].

In the framework of wholeness and implicate order model, the rotation of crystal planes in a three dimensional volume of the compressed crystal is introduced as the implicate order. This implicate order is enfolded in the image and is manifested itself into an explicate order in the form of a band of contrast (Figure 4a). Depending on the microscope operation conditions, this band of contrast can change its position, width, intensity and shape. Nevertheless, all forms of this band of contrast, i.e. all explicate orders, still represent the same implicate order, i.e. the same rotation of crystal planes in a three dimensional volume of the compressed crystal. Following the arguments of Bohm [2], the three dimensional volume inside the crystal is considered as a higher dimensional ground in which the implicate order prevails and out of which the lower dimensional projections (i.e. image and diffraction pattern) exist with their own explicate orders. Furthermore, the diffraction pattern closely resembles the hologram analogy of Bohm [2] such that the rotation of crystal planes is the enfolded implicate order within the recorded patterns and is unfolded through the rotation of patterns recorded in sequence from the crystal surface.

IMPLICATIONS FOR CONSCIOUSNESS STUDIES

> "…in my scientific and philosophical work, my main concern has been with understanding the nature of reality in general and of consciousness in particular as a coherent whole, which is never static or complete but which is an unending process of movement and unfoldment...perhaps because we have at present no coherent world view, there is a widespread tendency to ignore the psychological and social importance of such questions almost altogether.
>
> David Bohm [2]

Based on the two analogies described previously, one can consider the brain as the crystal and the stream of consciousness (or its contents) as the electron wave field inside the brain. The term *stream* is particularly relevant in this context since the electron beam can be considered as a stream of electrons interacting with the crystal. Considering consciousness as the electron wave field interacting with the brain as the crystal offers the possibility of defining consciousness based on the properties of the electrons and matter in a mathematical framework provided by the dynamical diffraction theory [13] described in the following.

If an incident electron wave satisfies the boundary conditions at the crystal-vacuum interface, it is transformed into a wave field inside the crystal. Replacing the crystal by the brain and contents of consciousness by the electron wave field, the question is then what are the characteristics of the electron wave field inside the brain and furthermore, what information does such electron wave field carry with respect to the contents of consciousness? This problem can be mathematically treated through considering the neurons in the brain as atomic planes in the crystal and the membrane potential of the neuron as the Coulomb potentials of the single atoms. Based on the dynamical diffraction theory [13], the wave function $\Psi(r)$ of the propagating electron within the brain with points r is expressed by Schrödinger equation, where m is the relativistic mass of the electron, e is the magnitude of the electron charge, h is the Planck's constant, E is the incident electron potential, and $V(r)$ is the periodic membrane potential of single neurons expanded as a Fourier series over all reciprocal points h which are defined in the spectral domain and are inversely proportional to the points r in real space.:

$$\boldsymbol{\nabla^2\Psi + \frac{8\pi^2 m|e|}{h^2}\,[E + V(r)]\Psi = 0} \qquad (1)$$

$$\boldsymbol{V(r) = \textstyle\sum_{-\infty}^{+\infty} V_h \exp(2\pi i h.r)} \qquad (2)$$

The solution of equation (1) exhibits the same fractal characteristics as the brain and can be written as a sum of scattered waves $\boldsymbol{\Psi^{(j)}}$:

$$\boldsymbol{\Psi(r) = \sum_j \in^{(j)} \varphi^{(j)} = \sum_j \in^{(j)} \sum_j C_g{}^{(j)}\ \exp\left[2\pi i\left(k_0{}^{(j)} + g\right).\ r\right] \exp(-2\pi q^{(j)} z)}$$

Where the $\in^{(j)}$ are the excitation amplitudes of the waves $\boldsymbol{\varphi}^{(j)}$ and the $\boldsymbol{C_g}^{(j)}$ are the amplitudes of the partial waves with wave vectors $\boldsymbol{k_g}^{(j)} = \boldsymbol{k_0}^{(j)} + \boldsymbol{g}$. The last term, containing the absorption parameters $\boldsymbol{q}^{(j)}$ expresses the exponential decrease of the wave amplitudes with increasing depth *z*. The indices *j* and *g* run over an infinite number of reciprocal lattice points. This treatment is consistent with Pribram's holographic notion of the brain [17]. The above proposal presents a number of insights into the study of consciousness as listed below.

1. The electron wave function has the same the same periodicity as the crystal. In other words, the implicate order enfolded inside the crystal is manifested itself into the electron wave. If consciousness is regarded as the electron wave and the crystal is regarded as matter, the wave solution of dynamical diffraction theory suggests that both consciousness and matter have the same implicate order i.e. same periodicity. This leads to the two following conclusions; first, consciousness can be understood in terms of the implicate order. Second, consciousness and matter are not separated from each other but connected together by means of a common implicate order. Both of these conclusions support the wholeness and implicate order model of Bohm [2].
2. The implicate order of crystal and the unfolded explicate orders of projections become apparent by means of the electron beam. Therefore, the electron beam is prior to the crystal and the projections since without the electron beam, the implicate order of crystal and the explicate orders of projections become non-existent. Similarly, consciousness is prior to all implicate and explicate orders since all implicate and explicate orders become non-existent without the stream of consciousness [2].
3. In SEM, the crystal is the observed and the detector forming the projections is the observer. The implicate order of crystal as the observed is enfolded in the electron beam and is unfolded into the explicate orders of projections as the observer. Similarly, the stream of consciousness forms and dissolves all *things* including the observer and the observed. This definition is consistent with the analogy of brain being the hardware, the mind being the software and consciousness being beyond both as defined by John C. Lilly in [18].
4. The electron beam of certain energy or convergence angle results in a certain projection while the electron beam of a different energy or convergence angle results in a different projection. This indicates that the implicate order of crystal and explicate order of projections are not separated by the properties of the electron beam. This implies that the implicate and explicate orders and the stream of consciousness are not separable and indeed, all exist in one undivided whole.

5. Through its interaction with the crystal, the electron beam is modulated to give the explicate orders. This means that the electron beam is affected by the implicate order of the crystal. Therefore, it is proposed that the stream of consciousness is constantly modified by the set of enfolded implicate orders. In other words, the stream of consciousness is affected by what it creates and dissolves.
6. The definition of consciousness in terms of an electron beam with the solution in the form of an electron wave function supports the arguments of Douglas Hofstadter in defining consciousness as a self-perceiving and self-inventing *strange loop* [19]. In the framework of reality and consciousness, the implicate and explicate orders are dynamically enfolding and unfolding in an undivided whole [2]. Each human being is an explicate order manifested by means of a stream of consciousness out of an enfolded implicate order.
7. Self-similarity is necessary in order to achieve a coherent phase in the scattered electron waves through phase modulations, similar to the self-similarity of a crystal over space. Diffraction patterns from a damaged crystal (for example, from a surface deformed by mechanical polish) becomes noisy due to many *out-of-phase* scattering events, since self-similarity is diminished by disturbed the periodicity of unit cells which are the building blocks of a crystal.
8. The subject/object (or observer/observed) differentiation is related to the frequency of the carrier wave in the brain. An example is found in Shewanella oneidensis which are the bacteria found in deep sea floors which survive high pressures up to a few GPa. It has been reported that the outer shell of the bacteria behaves differently depending on the frequency of pressure wave applied to them such that to low frequency pressure waves, the shell has a rubbery response and to high frequency shock waves, the shell behaves as a rigid body without "seeing/experiencing" the pressure. In other words, shock experiments bring more survivors compared to static pressure due to the time scale of pressure wave propagation [20]. This implies that if consciousness can be tuned to higher and higher frequencies, the reality response would get closer to the rubbery response of bacteria where the boundaries between the subjects and objects disappear and all become one flow which can reportedly also be achieved through long and intense periods of meditation or through psychedelic drug use [21].

In summary, the implicate and explicate orders are not separated from each other, instead, each set of implicate and explicate orders are bound together with the stream of consciousness creating them, dissolving them and changing them while effectively, being affected by both sets. Therefore, consciousness should be studied in terms of a set of implicate orders out of the space-time context as well as a set of explicate orders in limited contexts of space and time, all in one undivided whole.

CONCLUSIONS

The development and presentation of analogies in the field of materials science and engineering not only provide immediate insights into the meaning of the notions of wholeness, implicate and explicate order but further supports the model as a representation of reality and consciousness as one undivided whole. The well-developed and well-established theories, techniques and methods used by scientists and engineers help the community of consciousness researchers in their understanding and examination of the models proposed in physics and philosophy disciplines. Such better understanding would, in turn, pave the road for a coherent world view.

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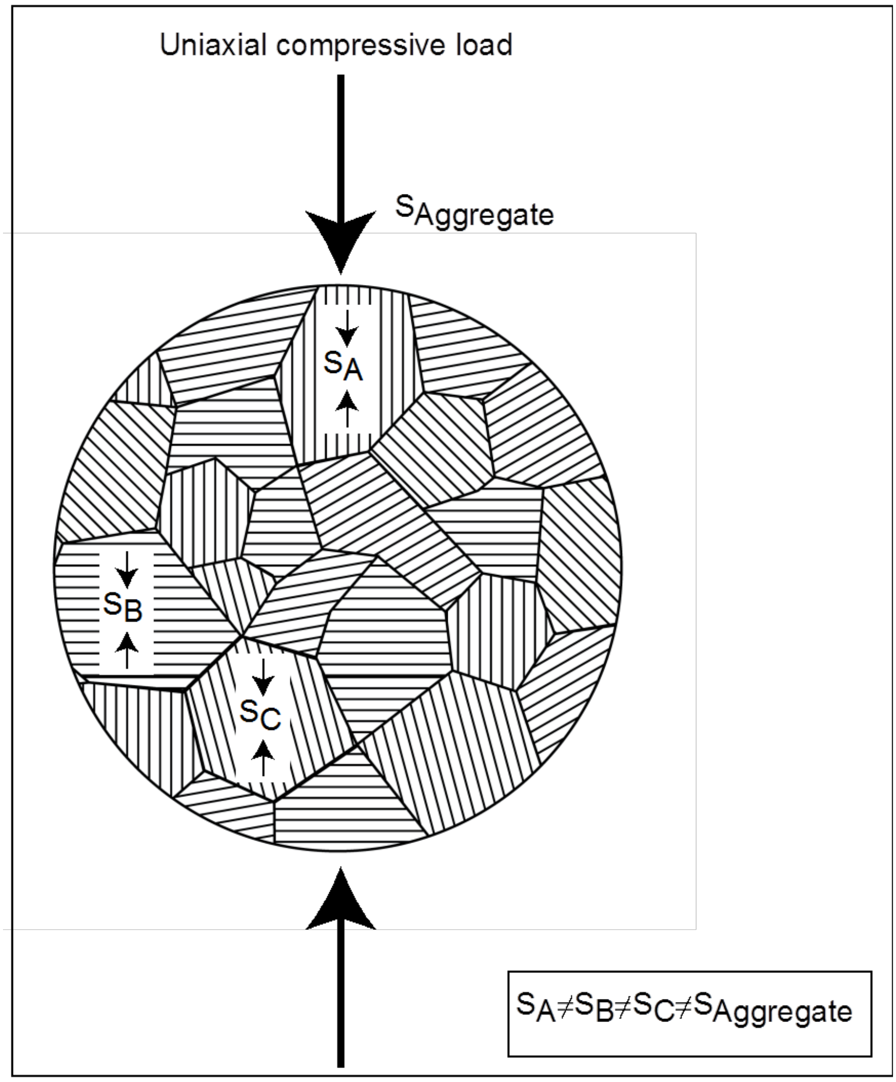

Figure 1. A schematic of a polycrystalline aggregate under a uniaxial compressive load. Three crystals of different orientation and size are indicated with *A*, *B*, *C*. The crystal planes are drawn as parallel lines inside each crystal. The stress of aggregate $S_{Aggregate}$ is different from the stress of each crystal ($S_A \neq S_B \neq S_C \neq S_{Aggregate}$). The aggregate and its constituent crystals together represent an undivided whole (adapted from [8]).

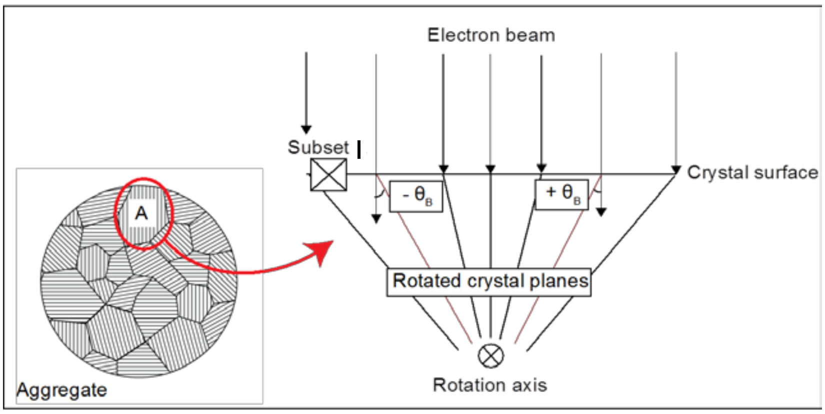

Figure 2. A schematic of rotated crystal planes in the near surface volume of a compressed crystal under an electron beam. The Bragg law of electron diffraction [13] is satisfied at crystal planes indicated in red. The θ_B represents Bragg angle. The rotation of crystal planes is introduced as the implicate order of a compressed crystal (adapted from figure 4 in [15]).

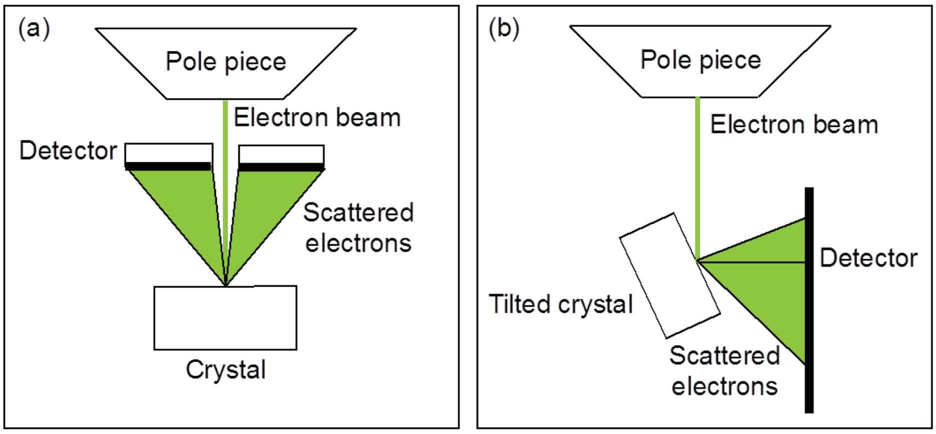

Figure 3. The schematic crystal-detector configurations for (a) imaging and (b) diffraction techniques in a scanning electron microscope (SEM) (adapted from figure 5 in [15]).

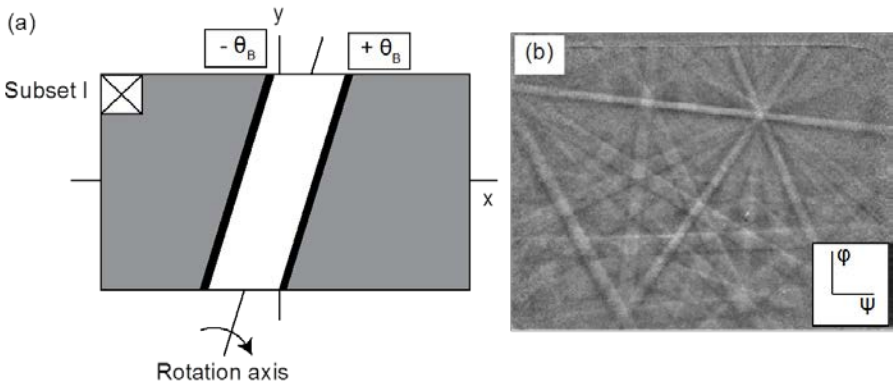

Figure 4. The results of a compressed crystal of magnesium examined in a scanning electron microscope (SEM). (a) A schematic image with a band of contrast parallel to the rotation axis. The edges of the band indicate the positions where the Bragg law of diffraction is satisfied. (b) An example diffraction pattern with bands and lines representing the three dimensional structure of the near surface volume of compressed crystal. There is one-to-one correspondence between the image in (a) and the crystal; for example, subset I in (a) corresponds to subset I in Figure 2. However, there is *no* one-to-one correspondence between the diffraction pattern in (b) and the crystal (adapted from Figure 4 in [15]).