BIBLIOGRAPHY OF ENVIRONMENTAL SCANNING ELECTRON MICROSCOPY

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Running title: **ESEM Bibliography**

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Key words: ESEM, Survey of ESEM, Review of ESEM, Development of ESEM, Uses of ESEM, Applications of ESEM.

Abstract Two updated lists of publications on environmental scanning electron microscopy are compiled. One list contains mainly those papers dealing with the development and instrumentation, while the other deals mainly with the applications of the technique. A brief introductory summary of the field is presented.

SUMMARY AND GENERAL REMARKS

The electron microscope has necessitated the presence of a good vacuum for the generation and propagation of the electron beam. This necessity has resulted in the positioning of the specimen itself in the same vacuum of the microscope. However, since the early beginnings of electron microscopy, there have been numerous attempts to operate the microscope with a gaseous environment around the specimen under examination, but, as a rule, the vacuum has remained the main condition of operation for this instrument. It is a relatively recent event that one particular form of the electron microscope, namely, the scanning electron microscope (SEM) has been made to allow a gaseous environment in its specimen chamber, which has resulted in what is now known as environmental scanning electron microscope (ESEM). It is a most recent event that the use of ESEM has been rapidly expanding as a result of the manufacture of the first commercial units. This expansion is evidenced from the large number of publications appearing over a short span of time. This has created the need to prepare and update a list with all those works relating both with the development and uses of ESEM, for the benefit of those working in the field.

Much of the work that preceded the development of ESEM has been of great value and assistance in our present understanding. These early works involve the transmission electron microscope and have been thoroughly reviewed by Parsons et al. (1974) and by Butler and Hale (1981).

Reviews of ESEM during its development have been published by Danilatos and Postle (1982b), and Danilatos (1988a; 1991a; 1993a).

Early attempts to operate an SEM with a gaseous environment involved a minimum of modification to the SEM. Thus, Lane (1970) made a specimen stub with a water reservoir which ejected a vapor jet to maintain a humid gas layer over the specimen, with no other modification to the microscope. Robinson (1974) used a wide angle scintillating backscattered electron detector in conjunction with a single pressure limiting aperture to separate the vacuum in the electron optics column from the humid environment close to the freezing point in the specimen chamber. Spivak et al. (1977) reported the use of environmental cells in the study of hydrated specimens. Shah and Beckett (1979) also used a differentially pumped environmental cell with the "specimen absorbed current" mode for detection. Surveys and discussions on those methods have been presented by Danilatos and Postle (1982b), and Danilatos (1988a; 1990c; 1990e; 1993a).

A steady development of the field of ESEM continued from 1979 to the present day with a series of papers by Danilatos. These works encompass all main modes of imaging, electron dynamics and gas dynamics. The optimum design and integration of detectors with electron optics and differential pumping constitutes the basic philosophy of these developments. Central to these is also the introduction of new detection methods such as the gaseous detection device (GDD). With this, both the secondary and the backscattered electron signal can be detected, in a variety of ways. The advancement of a proper theoretical background has also constituted the basis for much of the progress in the past, present and future. All this has culminated in the manufacture of the first commercial instrument of ESEM, which is now widely used in the most diverse applications.

A detailed discussion of these developments is omitted from this paper as the reader is presented with the opportunity to directly access all those works that have led to the current state of the art. To facilitate this survey, publications have been grouped in two categories: Those that mainly deal with the instrumentation, i.e. with the development of the machine itself, have been separated from those dealing with the applications and uses of the machine. More specifically, those papers that have resulted from the use of the commercial (ElectroScan) ESEM have been grouped together, with a few papers also containing some attempts towards the further development of the technique. All other publications involve the

development and use of experimental prototypes of ESEM, or deal with theoretical issues of the technology. The vast majority of present day ESEM users involve the commercial instrument, which binds them into a specific group with common interests. However, a better understanding of the technology will be assisted by consulting both bibliographical lists and, indeed, the readers are urged to do so.

Invariably, there must be a number of related papers that have not been included in the present lists. The reason for this is that this author either has not seen them, or they are just being published or being submitted for publication. An effort was made to include some of those submitted for publication for which information became available. It would be greatly appreciated if the authors of new publications could notify the present author, so that a new updated list be published in the near future.

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