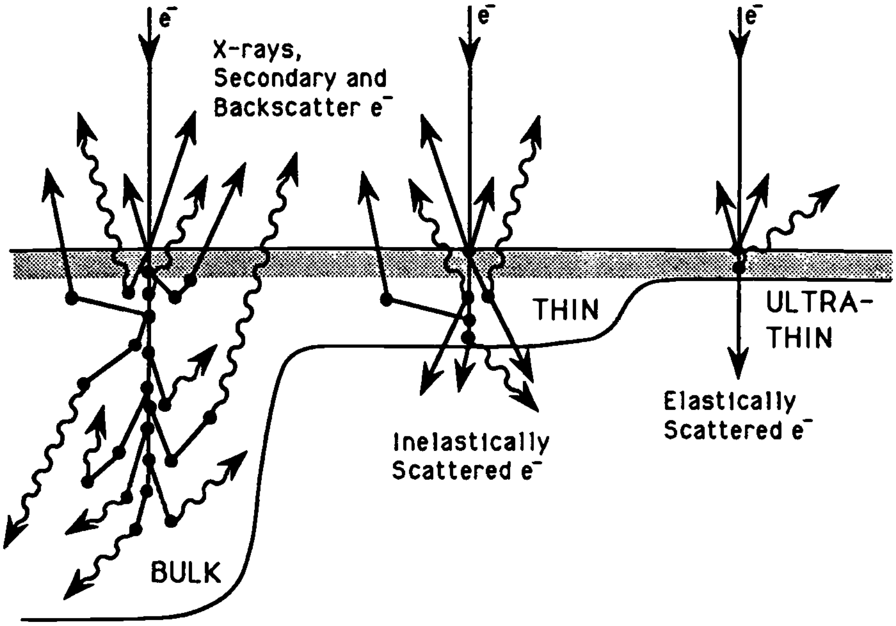

FIG. 1–Signal types generated by electron beams impinging on a sample of varying thickness. Adapted from Thomas [*1*].

the SE signal depends partly on the orientation of the sample with respect to the electron beam, which is why SE images are topographical.

Backscatter electrons (BE) result from elastic scattering. Electrons are elastically scattered when they penetrate the electron clouds of atoms and change direction, a result of coulombic interaction with the positively charged nuclei, known as Rutherford scattering. An electron is backscattered after a series of direction-changing elastic events that cause the electron to exit the sample. The probability of a backscatter event depends on the size of the nuclei and therefore backscatter contrast depends on the distribution of average atomic number in the sample. The depth in a sample from which BE information emerges ranges from about 80 nm for gold to about 600 nm for aluminum with an accelerating potential of 20 kV [*6*]. The yield of BE varies by only about 10% over an accelerating-potential range of 10 to 50 kV [*5*].

Most SEM images are collected with the Everhart-Thornley (ET) detector, shown in Fig. 3. The ET detector collects mostly SE and some BE. The main components of the ET detector are a collector grid, a scintillator, and a photomultiplier. SEs, whose average energy is about 3 to 5 eV [*5*], are pulled toward the scintillator by a 300-V potential on the collector grid. A 10-kV bias on the scintillator accelerates SEs enough to cause photon emission in the light pipe. The collection grid also protects the electron beam from deflection by the 10-kV bias on the scintillator.

Secondary electrons are classified into four types, shown schematically in Fig. 3. SE-1 are generated by direct interaction with the primary beam and therefore carry the highest resolution information. SE-2 are generated by backscatter electrons as they exit the sample surface and therefore generate sub-surface atomic number contrast. In 1940, before the first SEM images were collected, von Ardenne correctly predicted that SE-2 would limit resolution: SE-2 cannot be detected separately from SE-1. McMullan [*2*] wrote an historical account.

SE-3 are generated by backscatter electrons that strike the objective lens pole piece and the specimen chamber walls. SE-4 are generated when the primary beam strikes pole pieces and apertures. SE-3 generated at the objective lens pole piece can be reduced with a shield made of low SE-emitting material, such as carbon-coated aluminum, placed just below the objective lens. A +50-V bias, applied to the shield, also prevents escape from the shield of any SE-3. To increase atomic number contrast, BEs that strike the shield can be converted into SEs when the shield is positively biased or covered with a material that emits a large number of secondary electrons. Reimer [*6*] discussed signal types in detail. Peters [7] discussed high-resolution SE image formation.

There are two main types of BE detectors. One is the ET detector described above, an inefficient way to collect BE: the geometric collection efficiency of BE in an ET detector is only about 1 to 10% [*5*]. The efficiency is low because most BEs travel away from the sample in the beam direction, and ET detectors are usually mounted away from the beam axis. Collection efficiency is improved if a disk-shaped detector is placed at the bottom of the objective lens, with a hole in the middle for the electron beam. Both solid-state and scintillation-type detectors are used in this way.

To demonstrate the importance of understanding how SE1, SE2, SE3, and BE generate contrast in the SEM, three micrographs of the same area of a 1:6 styrene-butadiene latex:calcium carbonate coating formulation, air-dried from 80 wt%, are shown in Fig. 4. Micrographs in Figs. 4A and 4B were recorded at 20 and 5 kV, respectively, with an ET detector. In Fig. 4A, the calcium carbonate particles are visible from beneath the latex-film surface from a combination of SE-2, SE-3, and BE.

This is possible because the exit depth of BE from a latex film is about 1 μm at 20 kV. In Fig. 4B, the calcium carbonate