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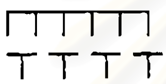
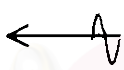
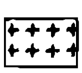
APPENDICES

APPENDIX 1

SYMBOLS

	Fault line
	Fault scarp
	Concave break of slope
	Concave change of slope
	Convex break of slope
	Convex change of slope
	Minor scarp
	Ridge
	Sharp valley
	Triangular facet
	Slope direction
	Stream, river
	Sink hole

(modified after McCalpin, 1996b & Demek, 1972)

			Village
	Clastic rock		Limestone
	Granite		Colluvium
	Alluvial deposite		

APPENDIX 2

Electron Spin Resonance (ESR) and Thermoluminescence (TL)

Electron Spin Resonance (ESR) or electron paramagnetic resonance (EPR) is a physical method of observing resonance absorption of microwave power by unpaired electron spins in a magnetic field. ESR was discovered by Zavoisky (1945) for transition metal ions in salts and developed after World War II using advances in microwave and solid sstate electronics. Prucell et al. (1946) and Bloch et al. (1946) discovered radiowave absorption by nuclear spins and developed a similar method, nuclear magnetic resonance (NMR). NMR is now widely used in chemistry and medicine. Computerized tomography NMR (CT-NMR) or magnetic resonance imaging (MRI), is widely used clinically because it is considered less hazardous than CT using X-rays. ESR or EPR, though less popular than NMR, is now used in radiation chemistry, biochemistry, solid state physics and medicine as a technique as common as infrared and visible absorption measurements.

A large number of books on ESR (EPR) have been published for physicists, chemists and biologists at both introductory and advanced levels. ESR spectra are usually characterized by the spin Hamiltonian parameters which are closely related to quantum physics. Those books contain the quantum physics concepts necessary for the analysis of ESR spectra and are not appropriate for geologists, archaeologists and anthropologists who simply want to apply ER or familiarize themselves with it as a dating or dosimetry method or as an imaging (microscope) tool in their own fields. The basic knowledge of ESR presented here can be understood without quantum mechanics, though methods for derivation of ESR spin Hamiltonian parameters are presented in the text. This is because ESSR signals must be identified using a few parameters to be sure that we are dealing with a specific type of unpaired electrons. ESR is by no means a difficult method for a non-specialist, which is why so many have begun to use ESR dating in addition to their own radiometric methods. A commercially available ESR spectrometer can operated by anyone with one hour's training.

Principles of ESR and TL Datings and Dosimetry

Natural radiation from radionuclides including uranium (^{238}U and ^{235}U(, thorium (^{232}Th) and their daughter radionuclides, and potassium (^{40}K) in the environment or inside an archaeological or geological material produces electronic and atomic defects in the material. The radiation produces Fred (unpaired) electrons, some of which may be trapped by impurities as well as by inherent defects. They are often quite stable and accumulate with time. These unpaired electrons may be in either the organic or inorganic portion and can be detected by ESR. The ESR signal intensity is proportional to the spin concentration and so to the total dose, i.e., the radiation dose rate and the time elapsed after their formation or an event, such as heating, which affects the spin concentration.

Thermoluminescence (TL) is observed when the trapped electrons (or holes) are released thermally and recombine with holes (or electrons) at an elevated temperature. On the other hand, ESSR detects unpaired electrons created by α-, β- and γ-rays. The direction of the unpaired electron spin (self-rotation), represented by a dancing girl and boy is changed by microwave absorption as the ESR signal intensity. These unpaired electrons trapped by an impurity or left at a hole are simply called "defects" in this book. The difference between TL and ESR dating is only in the detection method of defects from which "total dose of natural radiation (TD)" is obtained.

The TD is called the "archaeological dose (AD)" in archaeological applications and may be called the geological dose (GD)" in geological dating. "Accumulated dose of natural radiation (AD)" and "equivalent dose (ED)" are also used. For ESR dating we proposse "TD" ass a general term among these synonyms. We use the term "ED" for indicating experimentally obtained equivalent dose in this book. The radiation qualities or the energy spectra of the artificial and natural radiation are not the same and the defect production efficiency depends on the radiation quality. The ED is expressed as the dose equivalent to that of α-, β- and γ-rays used for the artificial irradiation. Hence, the obtained ED by artificial irradiation is not necessarily equal to the TD derived from natural radiation.

The TD depends on the age and "annual dose rate of natural radiation (D)". For the determination of ESR or TL ages from the TD or ED, separate assessment of the average D is necessary. The ESR age, T_{esr}, can be obtained by dividing the TD or ED with D, i.e.,

$$T_{esr} = TD/D \qquad \text{or} \qquad T_{esr} = ED/D$$

Both ESR and TL can be used as methods of radiation dosimetry since their signal intensities are proportional to TD or ED. TL dosimetry has been widely used in radiation facilities, while ESR dosimetry has not yet because of the absence of an appropriate dosimeter element and a low-cost light-weight reliable spectrometer. Such a spectrometer will increase the usage of ESR dating. The advantage that ESR measurements have is that they can be done without heating the material, which allows us to use tissue equivalent organic materials as a dosimeter element and biological materials to determine accident dose. Radiation dose of irradiated foodstuffs for preservation can be monitored with ESR.

The theory and standard procedures of ESR dating and dosimetry are described together with their limitation. A brief historical development of ESR dating and some technical notes are given at the end of this. It must be noted again that radiation assessment is necessary to obtain the ESR age. Obtaining the TD or ED is ESR dosimetry and only a part of ESR dating.

Summary

Physical and chemical principles have been described for understanding of conventional "absolute" dating methods. There are three categories of such dating methods; (1) decay of radioactivity, (2) natural radiation effects and (3) chemical reactions. ESR dating in geosciences belongs to category (2), since it utilizes natural radiation effects which have been accumulating since the formation of the material. Organic ESR dating in history and forensic sciences belongs to category (3). Since this book covers ESR dating and is not intended as a general text on dating in archaeology or geology, an extensive bibliography refers the reader to other works.

The time ranges that the major dating techniques are able to cover are summarized in Figure. The upper limit of our ESR dating and TL dating depends on the lifetime of the particular signal or peaks (defects), i.e., on the material used and impurities contained. Typical examples of carbonates and quartz are given. The lower limit depends on the sensitivity of the spectrometer and therefore will be improved considerably in the next decade.

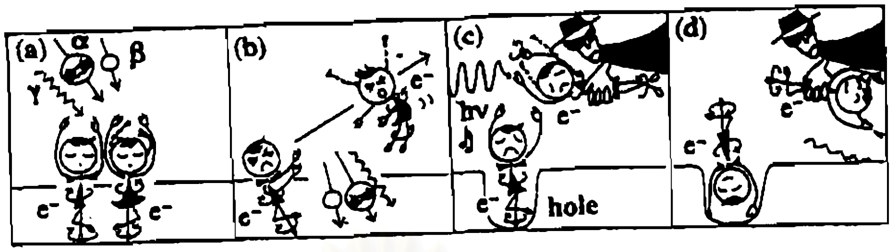


Figure 1 The principle of ESR dating. (a) Paired electrons are spinning in opposite directions, (b) ionization by α–, β– or γ–rays knocks off one of the paired electrons (girl) leaving the other (boy) in a hole, (c) the unpaired electron (girl) is trapped by an impurity (gangster), and (d) the spin direction of unpaired electrons is changed by microwave absorption. The concentration of unpaired electrons in proportion to the *TD* or *ED* is determined with ESR.

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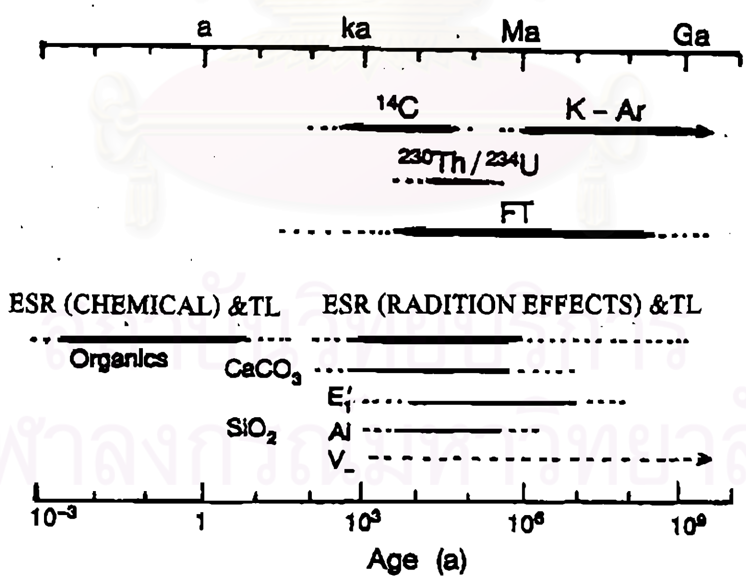

Figure 2 The time range of some dating methods.

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BIOGRAPHY

Mr. Krit Won-in was born on February 11, 1974 in Bangkok. He has finished the undergraduate study (Geology Program) and received the B.Sc. Degree from Department of Geology, Faculty of Science, Chulalongkorn University, since 1997. After that he studies the graduate program in geology at Graduate School, Chulalongkorn University.