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Exposure Charts for Radiography of Common Rock Types

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ABSTRACT.—X-ray radiography can be of significant value in the study of textures, structures, and fabric of rock specimens and unconsolidated sediments; but sample preparation, use of facilities available, and establishing correct exposure data may be costly in both time and materials. This paper outlines the basic techniques of radiography and presents exposure charts for making radiographs of the most common rock types.

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INTRODUCTION

X-ray radiography as a geologic tool is drawing increased interest in situations where it is necessary to examine rocks or sediments without destroying or disturbing structures. It is also useful for determining if hidden, incipient, or remnant fabric or textural features are present. Initial attempts to use radiography may be discouraging because of the several variables which must be considered in making an exposure. These include kilovoltage (Kv), milliamperage (ma), duration of exposure, specimen thickness, focus-film distance, and type of film. Determining the correct balance of these variables is time consuming and expensive if one is only examining a few specimens. For this reason we have included in this paper the basic steps and recommended exposures to use in making radiographs of the most common rock types. The procedures and exposure guides set forth here will not guarantee perfect radiographs each time because of variations in different X-ray machines; but the exposure charts will serve as a general guide and will considerably reduce setup time and film costs.

The graphs presented in this paper were developed while the writer was working on National Science Foundation Grant GP 1980. The Radiographic Division of the Eastman Kodak Company was especially helpful in preparing the exposure tables. The writer gratefully acknowledges the work of W. L. Chesser who drafted the illustrations.

EXPOSURE FACTORS

Radiographs of rocks may be made with either an industrial or medical X-ray machine by placing a slice of the specimen directly upon the film and exposing it to adequate radiation. The quality of the radiograph is a function of several variables which must be in proper balance if a correct exposure is to be obtained. Most important of these are (1) focus-film distance, (2) milliamperage, (3) exposure time, (4) kilovoltage, (5) type of material in the specimen, and (6) type of film.

Focus-Film Distance

When the X-ray output is constant, the radiation intensity reaching the specimen is governed by the distance between the tube and the specimen. *The intensity of radiation varies inversely with the square of this distance.* X-rays follow the laws of light in that they diverge when they are emitted from the anode and cover an increasingly larger area with less intensity. This inverse square law may be expressed algebraically as follows:

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2}$$

Where I_1 and I_2 are intensities at distances d_1 and d_2 respectively. Thus, to receive the same exposure of radiation at a focus-film distance of 24 inches as would be received at 12 inches, the radiation intensity must be increased four times.

Milliamperage and Time

The X-ray output is directly proportional to both milliamperage and time. The product of milliamperage and time is constant for the same photographic effect. This relation may be expressed as:

$$M_1 T_1 = M_2 T_2$$

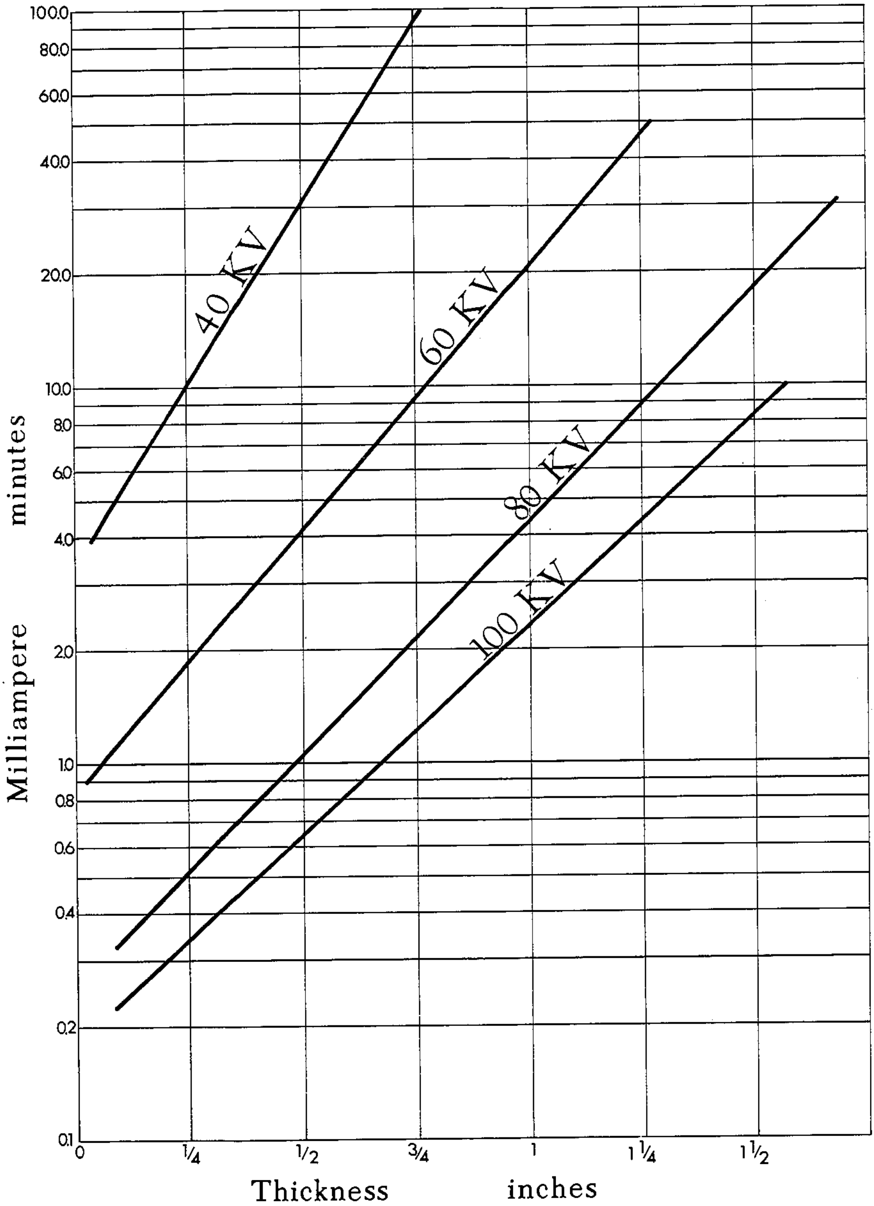
For example, if a good radiograph is obtained at 30 milliamperes in two seconds the correct time necessary if the milliamperage is changed to five, would be determined as follows:

$$30 \times 2 = 5 \times T_2$$
$$T_2 = 12 \text{ seconds}$$

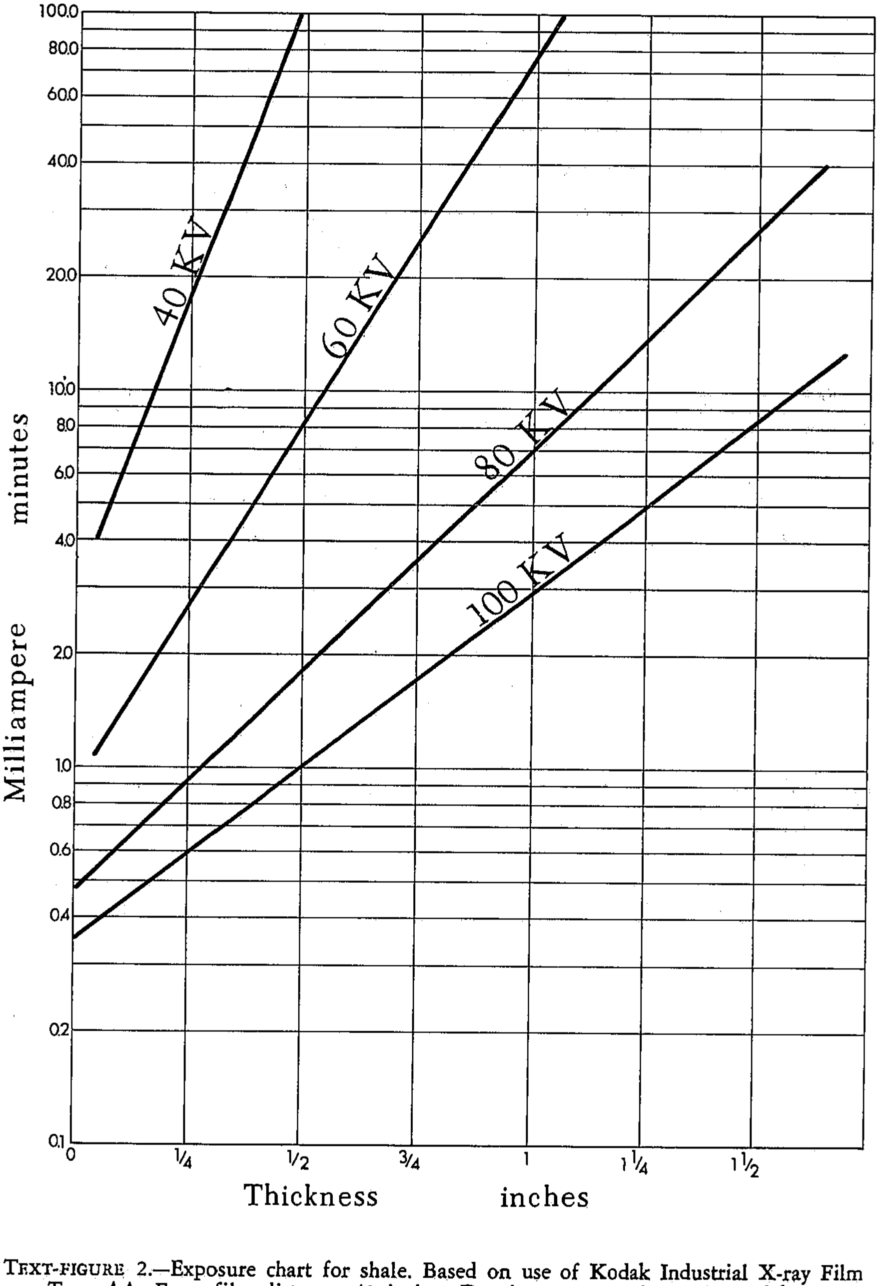
Kilovoltage

Kilovoltage governs the penetrating power of the X-rays and therefore governs the intensity of radiation passing through the specimen. It is not possible to specify a simple relation between kilovoltage and X-ray intensity because of such variables as thickness of specimen being radiographed, kind of material within the specimen, characteristics of the X-ray generating equipment, and film speed.

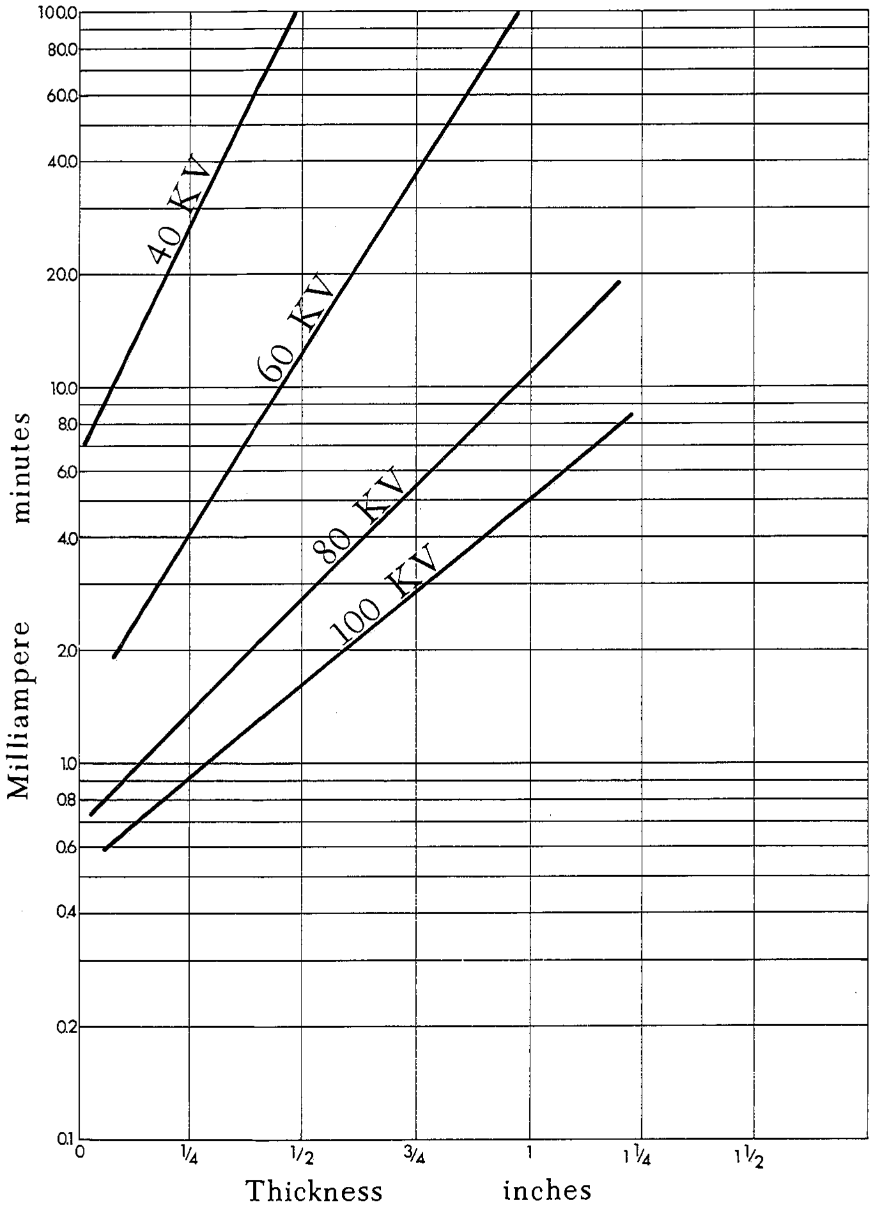
The exposure charts shown in Text-figures 1-8 show the relation between thickness, kilovoltage, and exposure (milliamperage x time) of 8 common rocks. These graphs are adequate for determining the general exposures but



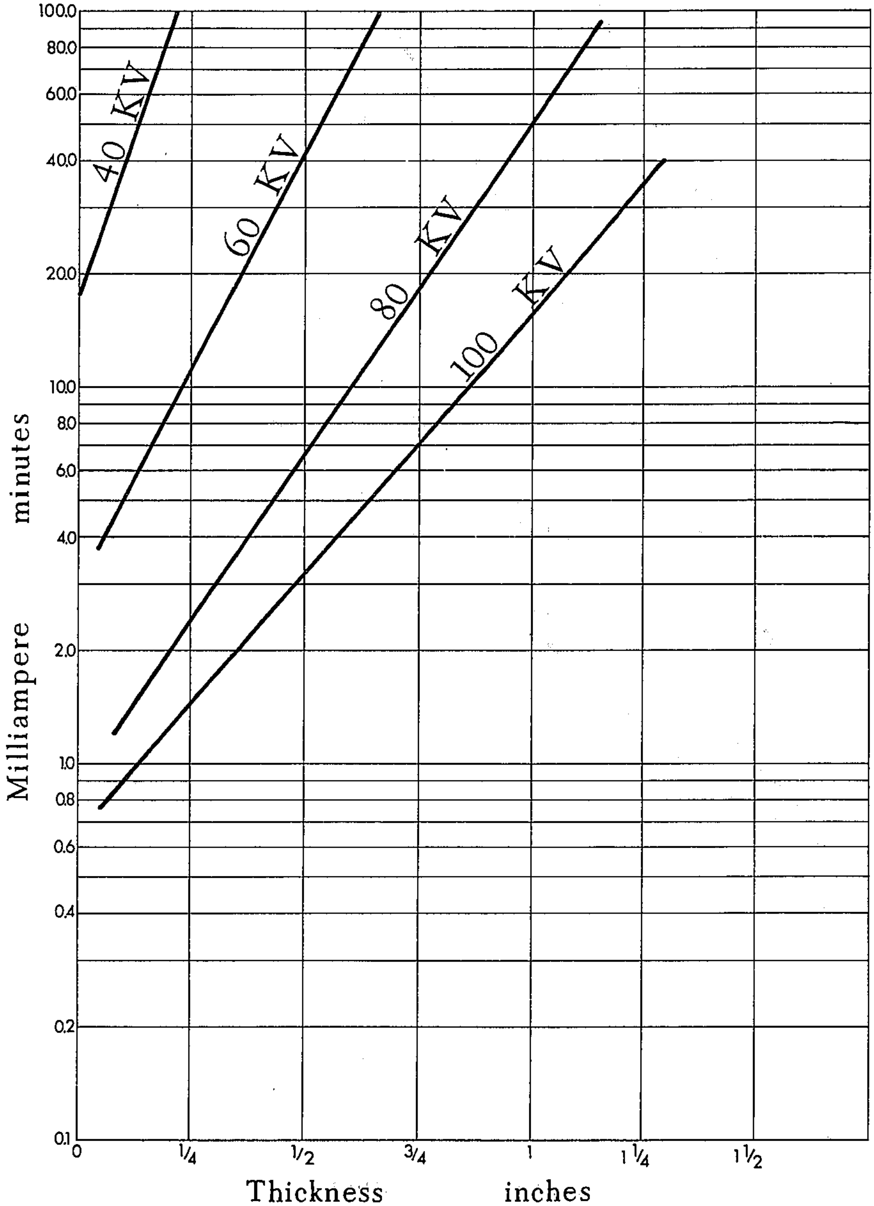
TEXT-FIGURE 1.—Exposure chart for sandstone. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.



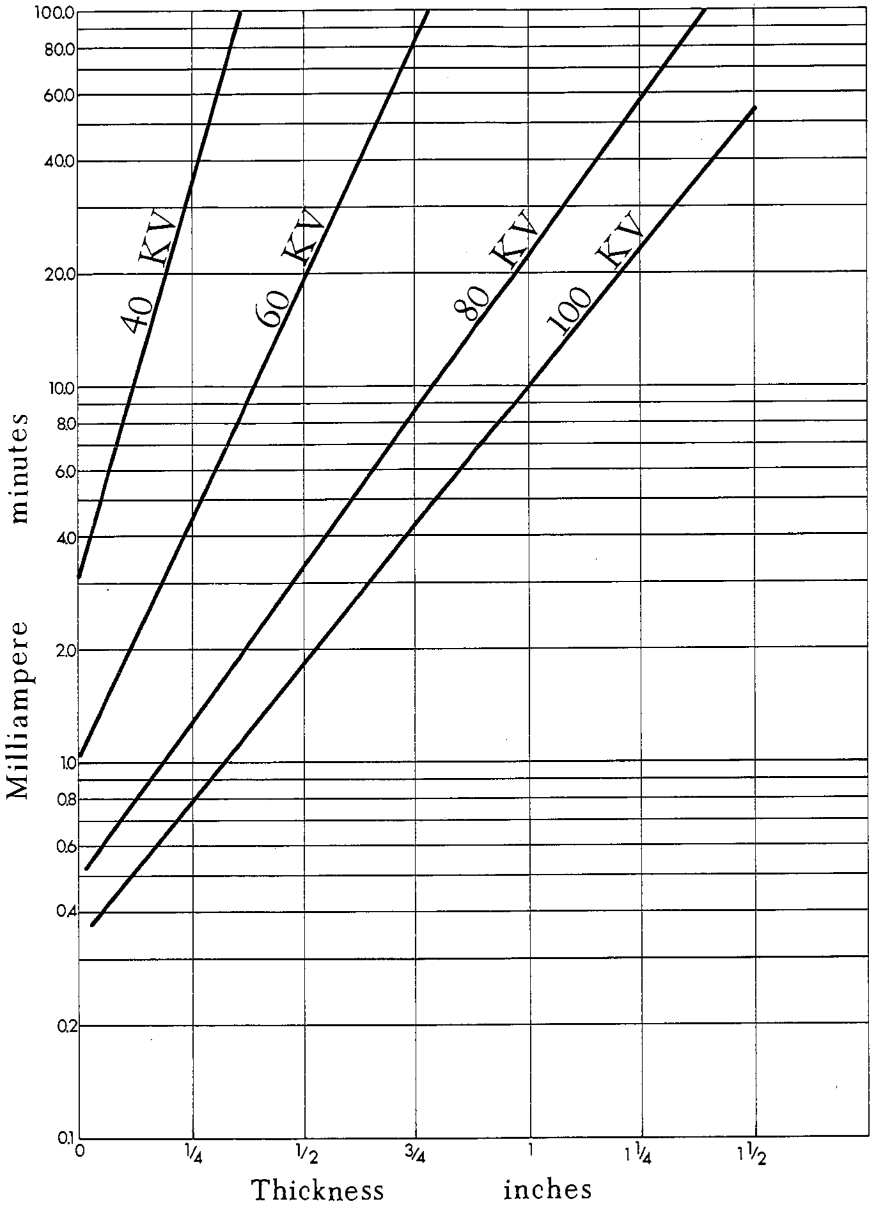
TEXT-FIGURE 2.—Exposure chart for shale. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.



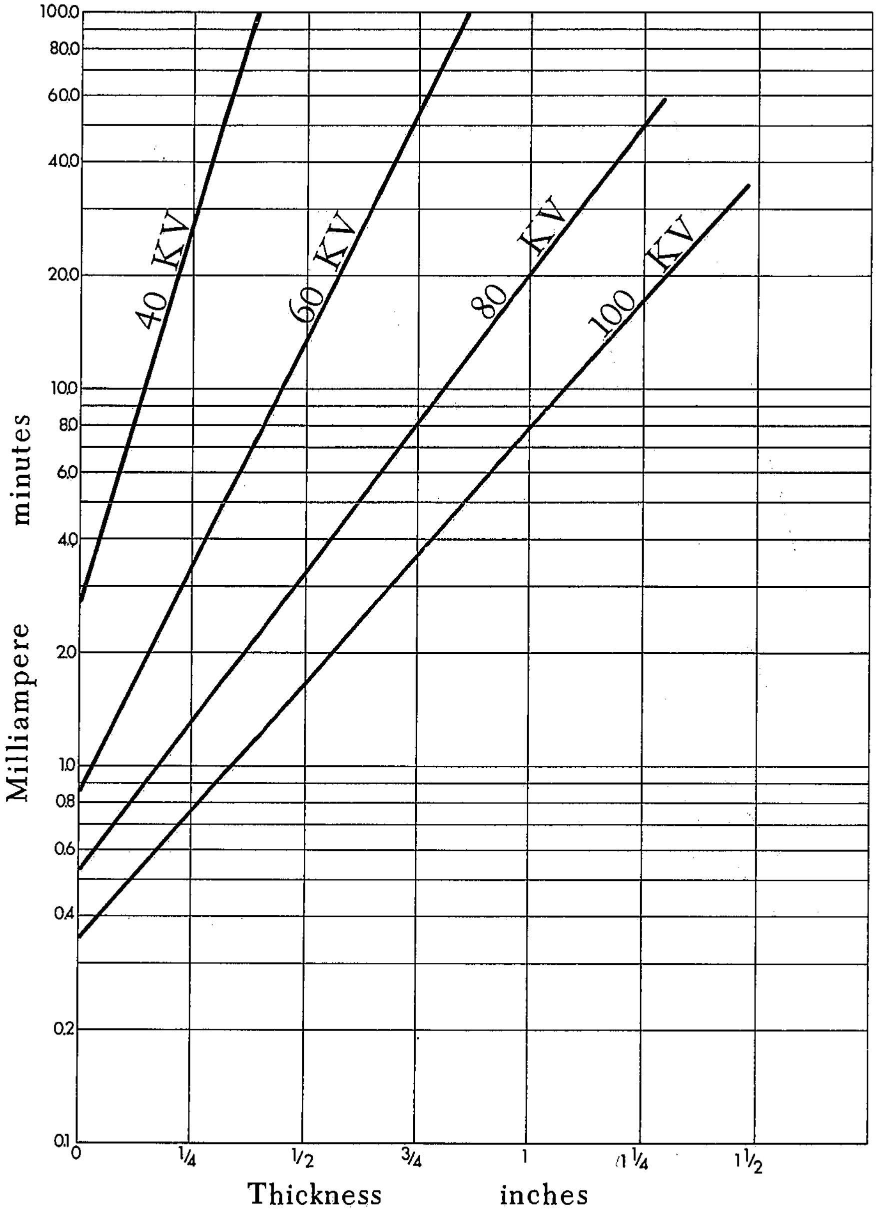
TEXT-FIGURE 3.—Exposure chart for calcareous shale. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.



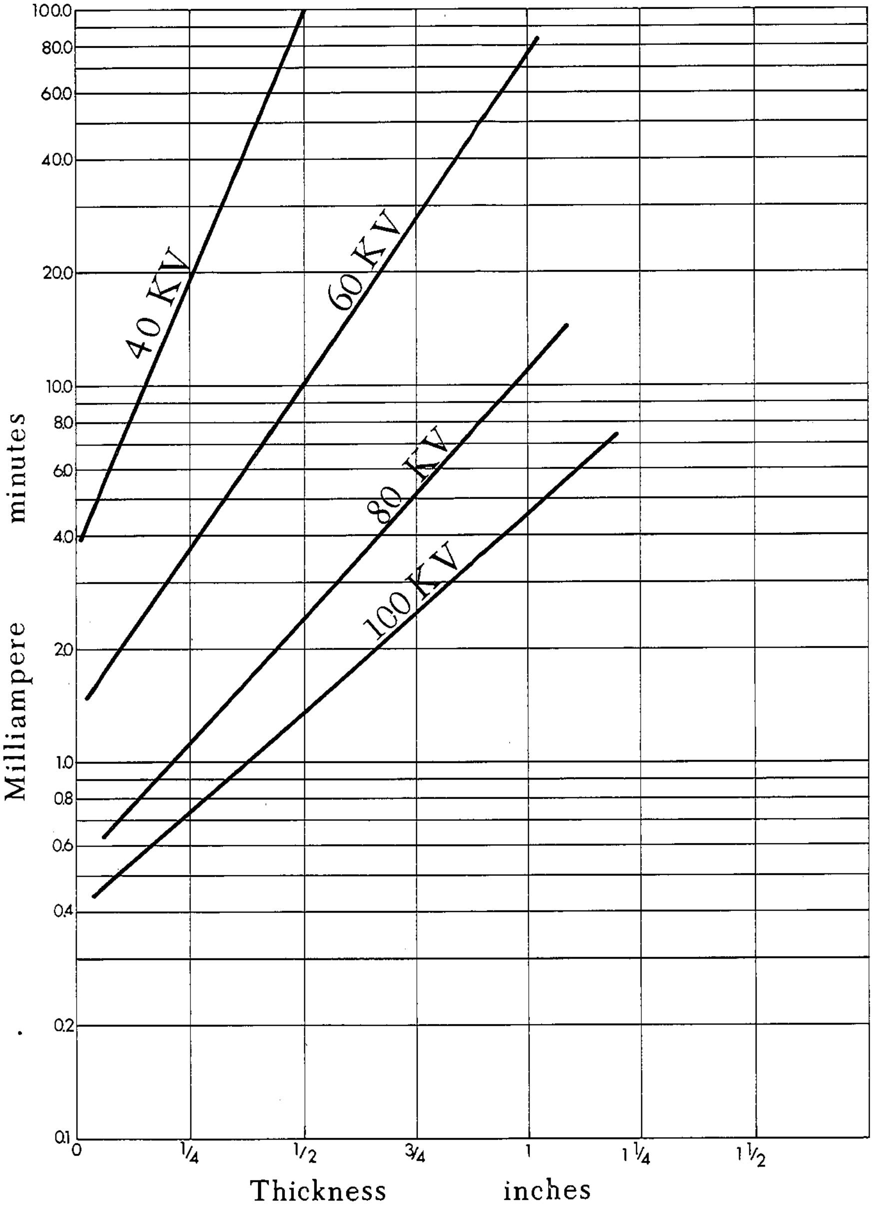
TEXT-FIGURE 4.—Exposure chart for limestone. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.



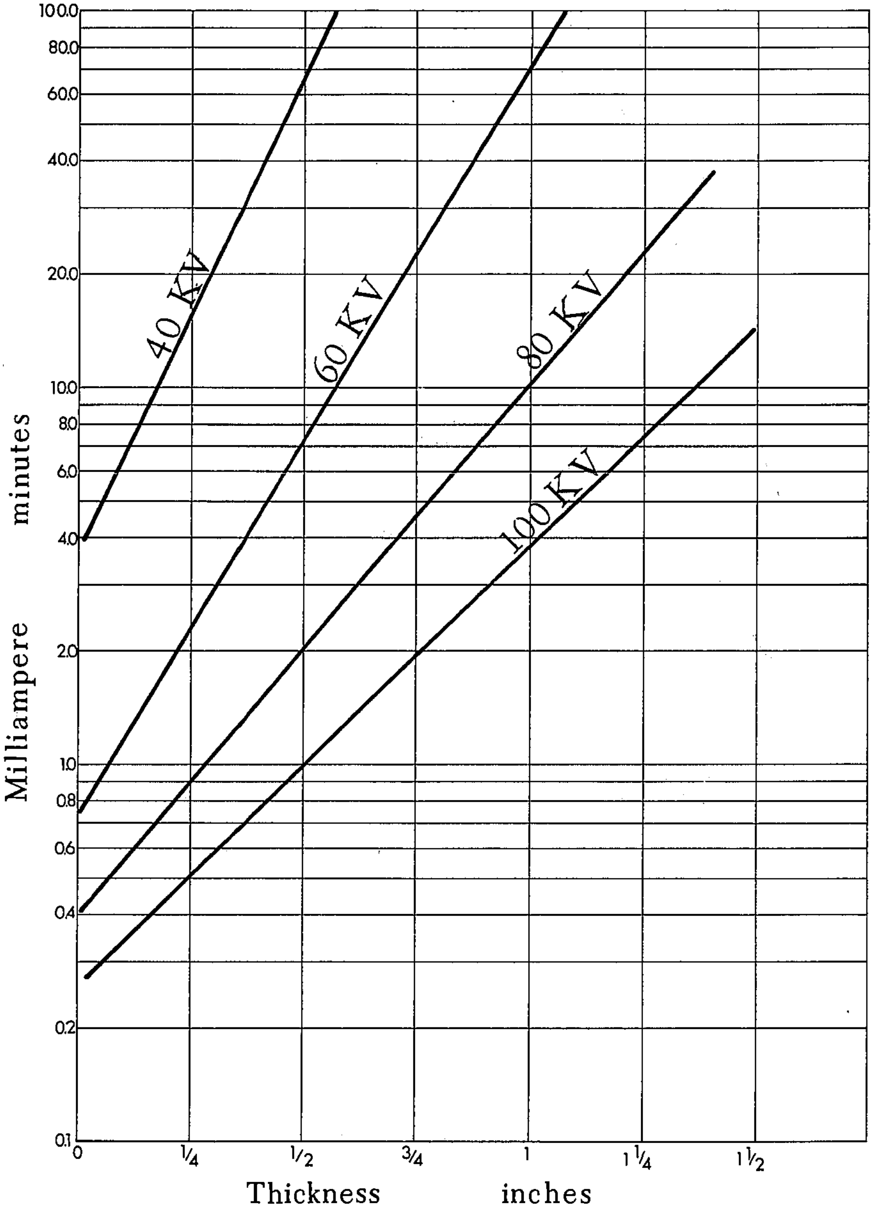
TEXT-FIGURE 5.—Exposure chart for basalt. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.



TEXT-FIGURE 6.—Exposure chart for andesite. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.



TEXT-FIGURE 7.—Exposure chart for granite. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.



TEXT-FIGURE 8.—Exposure chart for schist. Based on use of Kodak Industrial X-ray Film Type AA. Focus-film distance, 40 inches. Development, 5 minutes in Kodak Liquid X-ray Developer and Replenisher at 68° F.

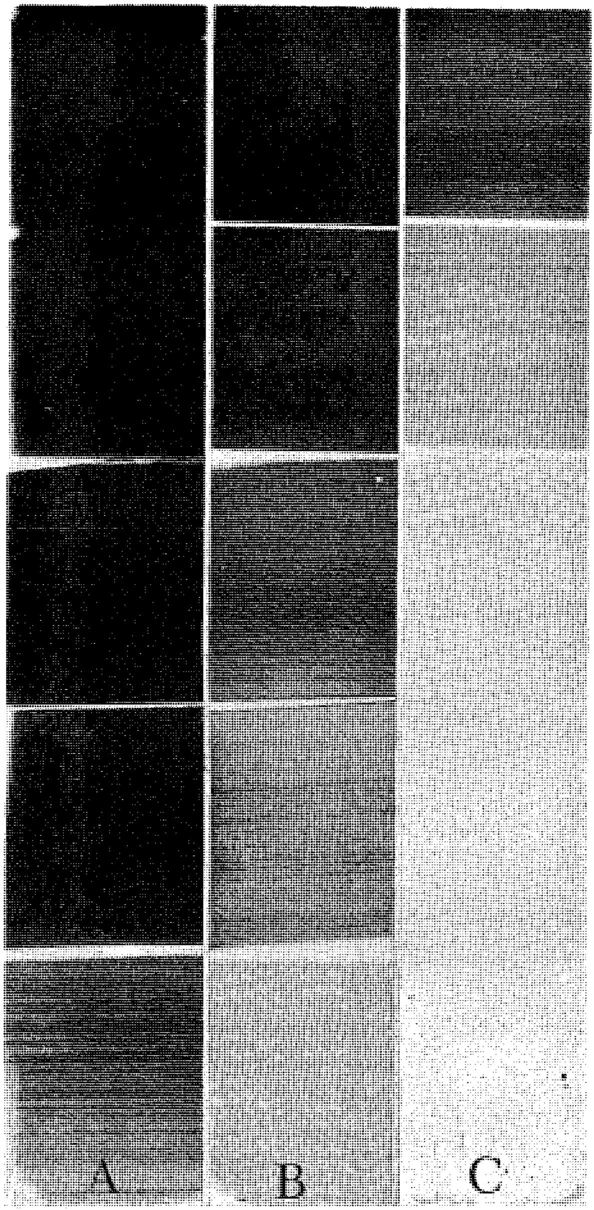
Table 1

EXPOSURE AND DEVELOPMENT OF KODAK INDUSTRIAL X-RAY FILM*

FILM TYPE	FILM CHARACTERISTICS	Contrast	Relative speed (5 min. Development)	Development for maximum speed	Speed increase with 8 min. development
Kodak Industrial X-ray Film TYPE R (Single-Coated)	Ultra fine grain and high contrast. The single-coated film has Type R emulsion on one side of the base only. Single-coated Type R is particularly useful if radiographs are viewed under high magnification.	High	7	8 min.	35%
Kodak Industrial X-ray Film TYPE R	Ultra fine grain and high contrast. Recommended when very fine detail is required. For use direct or with lead foil screens.	High	10	8 min.	35%
Kodak Industrial X-ray Film TYPE M	Extra fine grain and high contrast. Used to obtain high quality. Recommended when critical radiography is required. For use direct or with lead foil screens.	High	27	8 min.	40%
Kodak Industrial X-ray Film TYPE T	Extra fine grain and high contrast. Speed approximately half-way between Type **M** and Type AA. Particularly recommended for use in multiple film radiography and in single film techniques in which a film of both extra-fine grain and higher speed than Type **M** is indicated or a film of lower graininess than Type AA is required without too great a sacrifice in speed.	High	60	8 min.	30%

Kodak Industrial X-ray Film TYPE AA	Fine grain and high contrast. Its grain is not quite as fine as that of Type M, but its higher speed makes it more widely usable. For use direct or with lead foil screens.	High	100	8 min.	15%
Kodak Industrial X-ray Film TYPE F	Highest available speed and high contrast when used with fluorescent screens. Lower contrast when used direct or with lead foil screens. Records large range of thicknesses in relatively small density range.	Medium	200		
Kodak Industrial X-ray Film TYPE KK	Highest speed available when high voltage X-rays or gamma rays are used. For use direct or with lead foil screens.	Medium	630		
Kodak NO-SCREEN Medical X-ray Film	Speed and contrast similar to Type KK. Can be used direct or with lead foil screens.	Medium	630		

*Modified from *Radiography in Modern Industry Supplement No. 3,"* Eastman Kodak Co., Rochester, N. Y. 14650.



EXPLANATION OF PLATE 1

SANDSTONE RADIOGRAPHS OF VARIABLE EXPOSURE

Radiographs of sandstone stepped-wedge having a thickness range from 0.3 to 0.8 inches. The exposure was 40KV in *A*, 80KV in *B*, and 100 KV in *C*. Greatest detail is shown in the thin specimen exposed at lowest voltage. Detail and contrast in the thickest specimens (top of figure *C*) are obscurred because of hard radiation and distortion resulting from thickness of specimens.

cannot be used for different X-ray machines without a suitable correction factor. Considerable time and film may be saved however, by using the exposures recommended here as a starting point. The graphs were made from a series of specimens ranging from $\frac{1}{4}$ to $1\frac{1}{2}$ inches in thickness. Radiographs were made using several different exposure times at each kilovoltage and the proper exposure for each thickness determined.

Each exposure chart applies to a set of specific conditions; these are:

1. X-ray equipment used
2. focus-film distance
3. film type
4. film processing conditions

1. It may be difficult to determine the correction factor to make an exposure chart prepared for one X-ray machine applicable to another. Different machines operating at the same kilovoltage and milliamperage may not only produce different intensities but also different qualities of radiation. A certain amount of experimentation must therefore be used in order to utilize these charts for a particular X-ray unit.

2. Change in focus-film distance may be accomplished by using the inverse square law described above.

3. Different film types can be corrected by adjusting for the film speed. Table I gives the relative film speeds for Kodak industrial X-ray films.

4. Effective film speed is modified by changes in film processing. If the processing differs from that used in making the exposure chart a correction factor is necessary.

SAMPLE PREPARATION

The most useful radiographs will be obtained by using rock slices carefully prepared to assure even thickness. Even minor features, such as irregularities produced as the rock is sawed, will be recorded on the radiograph, so it is generally advisable to lightly polish the specimen and remove all saw marks.

The thickness of the rock slice may vary, depending on the features to be studied. In general, rock slices over one inch thick will result in poorly defined images, and specimens less than 2 mm will commonly lack sufficient density differences to produce a good radiograph. We have found that good definitions of internal fabric and structure of most rock specimens are obtained with rock slices ranging from 3 mm to 1 mm in thickness. An exception to these recommendations will be encountered with materials which absorb large amounts of radiation, such as limestone and metallic minerals.

CONTRAST

Radiographic contrast depends upon (1) contrast in absorption of radiation by materials within the specimen, (2) film contrast, and (3) wave length of the X-rays.

Unless there are inhomogeneities within the specimen there will be very low contrast produced on the film. Greatest contrasts are produced from rocks containing quartz and calcite, or quartz and ferromagnesium minerals.

In a given specimen, low contrast is produced by short wave-length (hard) X-rays and high contrast by longer wave-length (soft) X-rays. This principle is clearly illustrated in Plate 1 which shows three radiographs of sandstone samples ranging from 1 mm to 2 cm in thickness. Radiograph C was exposed at a high tube voltage and radiograph A and B at a lower voltage. It is apparent that more subtle details can be detected from thin specimens exposed at low voltage (A) than with thicker specimens where higher voltage is necessary for penetration.

High kilovoltage produces short wave-length X-rays which penetrate the specimen too readily. This decreases the contrast by increasing scatter. Therefore, the lowest kilovoltage which will penetrate the specimen and properly expose the film should be used. Greatest contrast can be produced by using an X-ray machine with a beryllium window which allows transmission of only the longer, soft wave-lengths.

In general, greatest detail in radiography of rock specimens may be obtained from high contrast film with slower speeds and a minimum of graininess. Slow-speed films require greater exposure times but are superior to films requiring shorter exposures which produce fuzzy, grainy radiographs.

PROCESSING X-RAY FILM

Procedures for developing X-ray film are essentially the same as those for photographic film except that most X-ray film has emulsion on both sides and hence tank developing is advised. Proper chemicals, recommended time, and temperatures are supplied by the film manufacturer.

Contact prints or enlargements can be made from X-ray films, but prints made from X-ray film seldom show all of the details recorded on the negative. The reason for this is the tremendous range of contrasts present on the radiograph.

Reproductions of radiographs as positives, or negatives, can be made using Kodak autopositive materials.

To project radiographs on a screen one may use the original film with an overhead projector or mount part of the negative between glass as a lantern slide. Standard 2 x 2 slides can be copied from a radiograph by photographing it on a light table. This can be accomplished with either Kodachrome film for color slides or a slow-speed copy film such as Panatomic-X. If the latter is used, it can be processed either as a normal or reverse negative.

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