Rainier Mesa-11

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Federal Center, Denver, Colorado 80225

SCHMIDT HAMMER TEST METHOD FOR FIELD DETERMINATION OF PHYSICAL PROPERTIES OF ZEOLITIZED TUFF

Open-file report
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1. Schmidt hammer test method for field determination of physical properties of zeolitized tuff, by John R. Ege, Danny R. Miller, and Walter Danilchik. 37 p., including 19 figs., 1 table. (*)

2. A geochemical evaluation of the Ash Sha'ib mineral prospect, Asir quadrangle, Kingdom of Saudi Arabia, by Glenn H. Allcott. 38 p., 6 pl., 3 figs., 6 tables.

3. Preliminary geophysical investigation of the Esh Qay'ib (Esh Sha'ib) mine area, Saudi Arabia, by Willard E. Davis and Hisham Kazzaz. 10 p., 6 figs.

4. Recommended geophysical investigations of mineral occurrences at Jabal Samran, Al Marasia, and Wutaileh, by D. H. Hase, V. J. Flanigan, and M. N. Akhrass. 5 p., 1 map, scale 1:500,000.

5. Qualitative analysis of airborne magnetometer data: The Arabian Shield, Kingdom of Saudi Arabia, by Donald H. Hase. 44 p., 1 pl.

6. Preliminary investigation of cement materials in the Taif area, Saudi Arabia, by Conrad Martin. 18 p., 1 fig., 1 table.

7. An appraisal of the Jabal Idsas magnetite mineralization based on diamond drill hole N40A, by Conrad Martin. 29 p., 4 figs., 1 table.

8. Geological reconnaissance of the western part of the Wadi Ar Rimah quadrangle, Saudi Arabia, by James W. Mytton. 3 p.

9. Reconnaissance of mineral deposits in the Precambrian rocks of the Wadi Ar Rimah quadrangle, Kingdom of Saudi Arabia, by James W. Mytton. 76 p., 1 pl., 3 figs., 3 tables.

10. Preliminary report on the Dawadami district, Saudi Arabia, by Paul K. Theobald, Jr. 4 p.

(*) <u>Note</u>: Item 1, above, is also available for inspection at 504 Custom House, San Francisco, Calif. 94111; 7638 Federal Bldg., Los Angeles, Calif. 90012; 1012 Federal Bldg., Denver, Colo. 80202; 8102 Federal Office Bldg., Salt Lake City, Utah; and in the Library, Mackay School of Mines, University of Nevada, Reno, Nev. 89507.

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SCHMIDT HAMMER TEST METHOD FOR FIELD DETERMINATION OF PHYSICAL PROPERTIES OF ZEOLITIZED TUFF

By

John R. Ege, Danny R. Miller,
and Walter Danilchik

ABSTRACT

The L-type Schmidt hammer is a hand-carried impact instrument that was originally designed and developed to test the compressive strength of concrete. When properly impacted against a stiff material the device measures the amount of rebound of a spring-loaded hammer, with the rebound of the hammer being directly proportional to the strength of the material tested. Application of this instrument to rock, specifically water-saturated zeolitized tuff, is demonstrated through a set of correlation diagrams that relate Schmidt hammer rebound values, obtained from core samples and from the sites where samples were taken, to physical properties measured on rock samples in the laboratory. The properties include compressive strength, compressional and shear velocities, and dynamic and static Young's shear and bulk moduli. The correlation diagrams apply only to zeolitized tuff of the type found at the Nevada Test Site in its natural state (freshly excavated). These diagrams enable the user of the L-type Schmidt hammer to immediately obtain values of physical properties of such rocks in place, a convenience desirable where conventional sampling is not feasible or is impossible, and when results are required

on short notice. The charts apply to L-type hammers that are calibrated to a nominal rebound value of 74. Calibration is made on a 35-pound- (16-kg-) test anvil with a steel-hardened test surface of Brinell hardness = 500 $\frac{kg}{mm^2}$.

INTRODUCTION

The objective of this study was to develop a fast, precise, simple, and cheap method of obtaining physical-property measurements of natural-state zeolitized tuff at the Nevada Test Site (fig. 1). The method, to be effective, would have to allow the testing of rock along tunnel walls, on outcrops, and from drill cores soon after removal from the core barrels. The test results would also have to be available almost immediately after the measurements were taken.

Deere and Miller (1966) established a relation between rock compressive strength, Young's modulus, and Schmidt hammer values for a wide range of rock types in dry state. The use of the Schmidt hammer, a small hand-carried spring-loaded testing instrument, would be an ideal way to obtain measurements of rock properties for Defense Atomic Support Agency (DASA), Atomic Energy Commission (AEC), and Sandia Laboratories, provided a good correlation could be established between Schmidt hammer values and natural-state properties for tuffs at the Nevada Test Site.

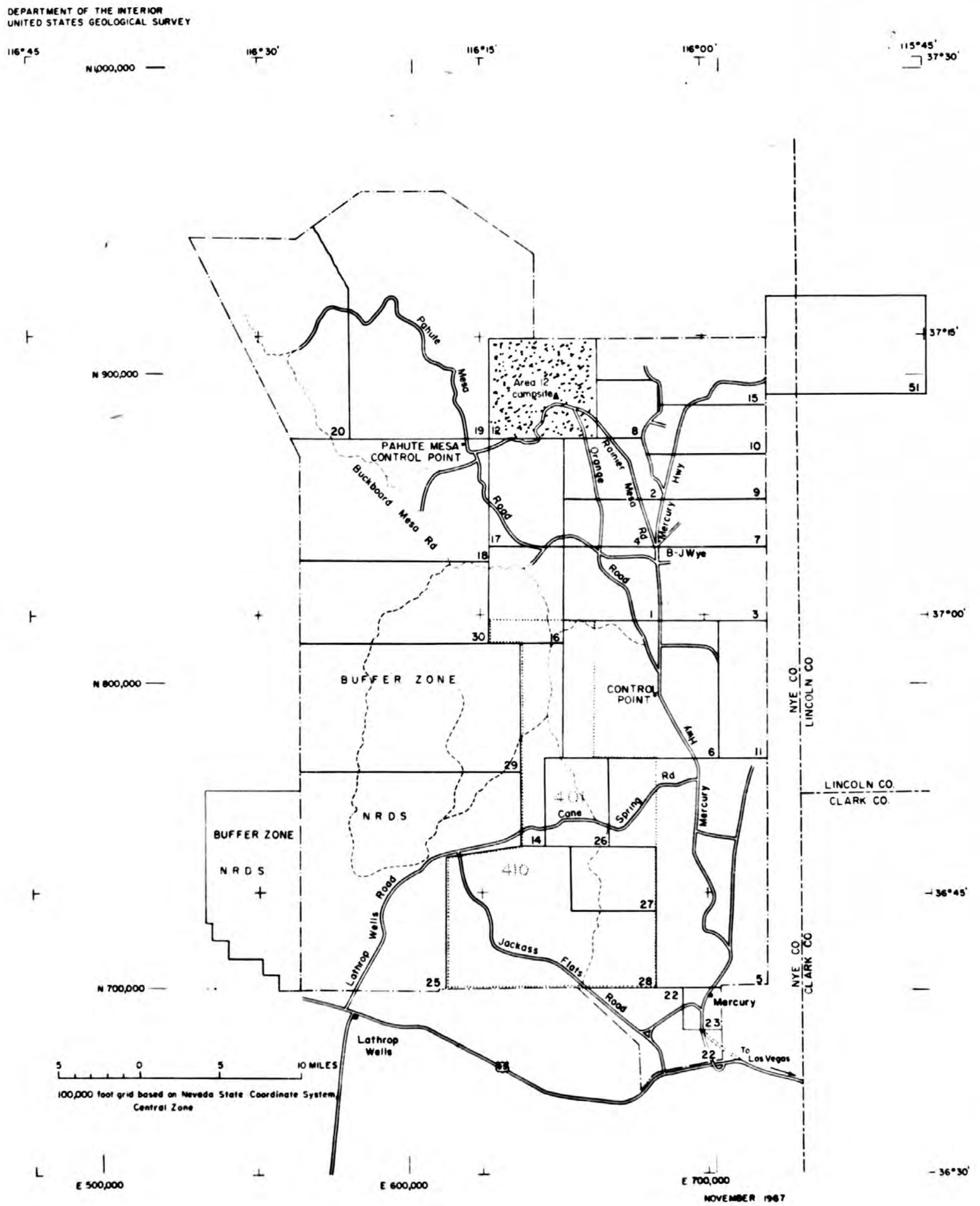

Figure I--Location map of the Nevada Test Site. Stippling shows area of study.

DESCRIPTION OF SCHMIDT HAMMER

The Schmidt hammer was invented in 1948 by Ernst Schmidt, a Swiss engineer, for the purpose of determining compressive strengths of concrete. It had been established that a direct relationship exists between the rebound of a steel hammer and the compressive strength of concrete; that is, a strong concrete will cause a steel hammer to rebound a greater distance than a weaker concrete will. Dr. Schmidt developed the spring-loaded hammer, which directly relates the magnitude of this rebound in terms of rebound numbers to concrete compressive strength.

The L-type Schmidt hammer consists of a cylinder about 2 inches (5 cm) in diameter and 10 inches (25 cm) in length. The cylinder houses a spring, plunger, and hammer assembly (fig. 2). The total weight is about 1.75 pounds (0.8 kg). The impact plunger is slightly convex at its end and is 0.6 inch (1.5 cm) in diameter. As the impact plunger is pressed against a test sample the impact spring is stretched. At a certain point a pawl releases the hammer mass which is then driven against the impact plunger. The L-type Schmidt hammer mass produces 0.54 foot-pounds (0.075 m-kg) of impact energy. Depending on the sample properties the hammer will rebound a certain distance after impact. The amount of rebound measured on an attached scale can generally be related to various physical properties of stiff (nonplastic) materials.

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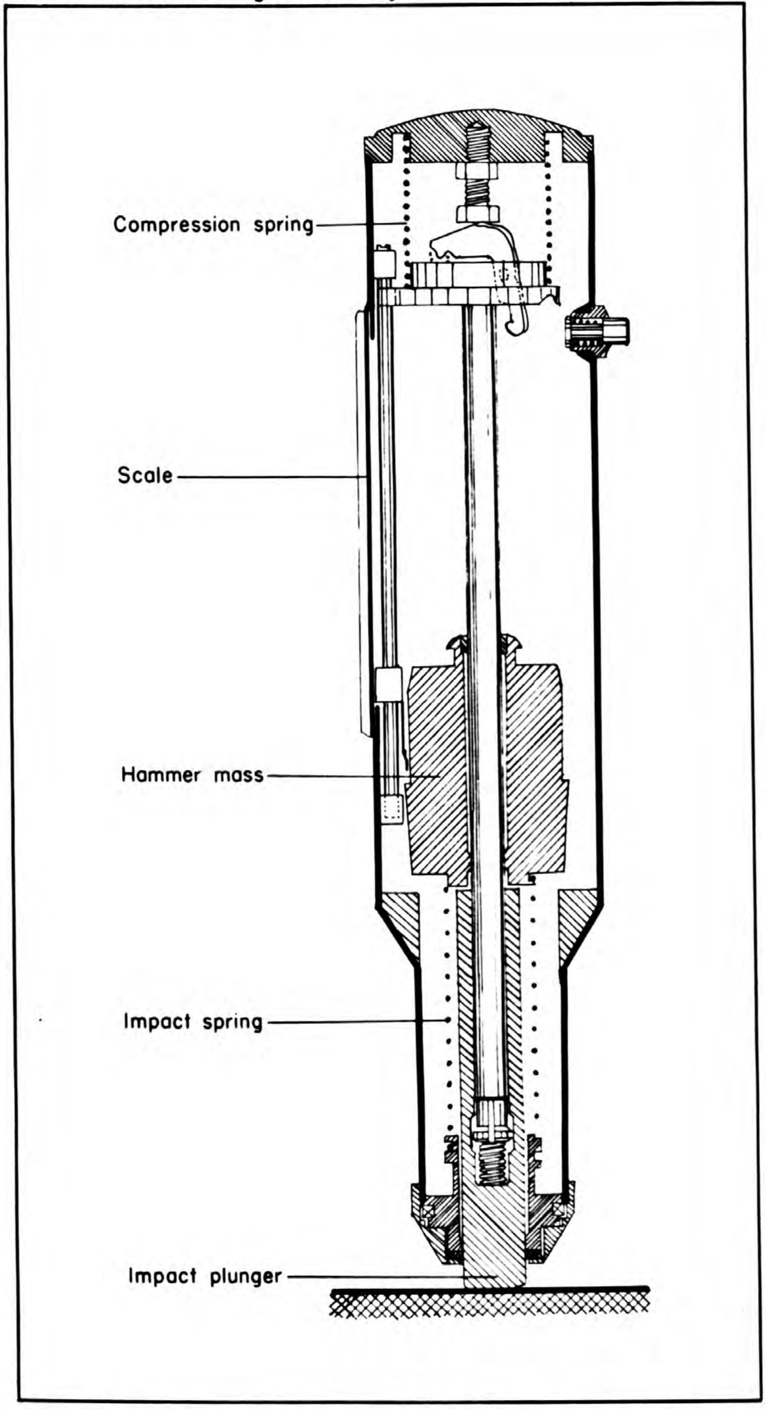


Figure 2--Longitudinal section of the Schmidt hammer, Illustration reproduced through the courtesy of A. Eisenhut, (Eisenhut, 1968, Operating Instructions--Concrete Test Hammer, Type L: Basle, Switzerland,)

Other models of the Schmidt hammer are manufactured. The difference between models is based on the amount of impact energy produced by the spring.

TEST PROCEDURE

The testing procedure recommended in this report generally follows that suggested by Deere and Miller (1966).

In applying the Schmidt hammer to zeolitized tuffs, five factors that affect the results of the readings must be considered.

1. Surface roughness.

The surface texture of the test specimen controls the completeness of contact between the 0.6-inch- (1.5 cm-) diameter head of the plunger and the sample surface. A smooth surface exposes a greater area to the head of the plunger as opposed to an uneven surface. If full contact is not maintained, the readings will generally be lower and, therefore, spurious.

2. The degree of water saturation of the rock.

Zeolitized tuff has the property of holding and retaining moisture because of its high porosity (20-50 percent), low permeability, and the hydrophilic zeolite and clay minerals that compose its lithology. Zeolitic tuffs, similar to clay soils, gain strength with loss of moisture. Water-saturated tuffs generally have lower compressive strengths than dry tuffs and correspondingly lower hammer readings than dry tuff.

3. The distribution and type of foreign rock fragments contained in the tuff specimen.

Lithic fragments, pieces of foreign rock interspersed throughout many tuff formations, normally have different properties from the surrounding matrix. The lithic fragments are analogous to concrete aggregate and do not contribute appreciably to the strength of the tuff. The lithic fragments contained within Nevada Test Site tuffs are mostly from harder rocks, such as rhyolite. For example, if the hammer were placed over a rhyolitic fragment, the resulting rebound number would be higher than that produced by the tuffaceous host rock and, consequently, not representative of the whole rock.

4. Fractures and spall sheets.

Fractures and spall sheets in the tuff can attenuate the impact energy transmitted by the hammer and may lead to lower than normal rebound numbers for the particular sample being tested.

5. Calibration of the instrument.

Proper calibration and cleanness of the internal parts of the L-type Schmidt hammer are essential if precise measurements are to be obtained. The manufacturer's operating instructions (Eisenhut, A., 1968, Operating instructions--Concrete test hammer, Type L, Hegenheimerstrasse 24, 4000 Basle, Switzerland) describe service and adjusting procedures. A special 35-pound- (16-kg-) testing anvil with a steel-hardened test surface (Brinell hardness = 500 $\frac{kg}{mm^2}$) is available commercially; this anvil can be used to calibrate the L-type Schmidt hammer to a nominal rebound value of 74 (fig. 3). Other heavy, smooth-surfaced, homogeneous blocks of material, such as a blacksmith's anvil or natural stone, can be used. If the special test anvil is not used, then a correctly calibrated Schmidt hammer should be tested on a substitute calibration block and a calibration value established for that material.

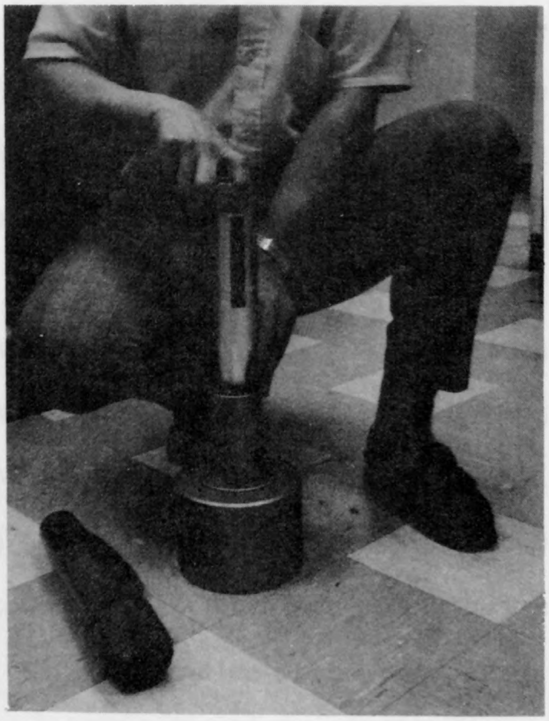


Figure 3--Calibration anvil for the Schmidt hammer.

On testing either a core sample or in-place rock, a total of 25 rebound numbers is taken on each sample. No selectivity is exercised in the course of hammering, except to avoid rock that is obviously part of a spall sheet, or that is locally much fractured (<3-inch joint spacing), or spots that have been previously hammered. An in-place test yielding 25 numbers usually requires an exposure of as much as 2 feet (0.6 m) on a side of representative rock.

With the exception of the obviously invalid readings that occur when the hammer is badly positioned, all numbers are recorded. The 25 numbers are ranked in order of magnitude; the lower 12 are discarded and the median value of the remaining 13 rebound numbers is taken as the rebound value for the specimen.

Discarding the lower 12 numbers eliminates low rebound numbers caused by such factors as operator error, poor instrument contact, and spall sheets. Using the median value instead of the arithmetic mean cancels any excessively high nonrepresentative numbers such as might be produced by a very hard dense lithic fragment.

There are, therefore, two quantities that are derived from the Schmidt hammer test. The <u>rebound number</u> is the quantity read directly from the hammer's scale after each impact, for which there are 25 rebound numbers per test sample. The <u>rebound value</u> is the median value of the 13 highest rebound numbers and is the single quantity that represents the sample. The rebound values as related to physical properties are shown on figures 6-19.

An example of a calculation of a Schmidt hammer value from Schmidt hammer numbers is presented below for tuff at C.S. (Construction Station) 1303 in the U12g.09 drift.

Schmidt hammer test

Moderate-reddish-brown tuff. C.S. 1303, left wall, U12g.09 drift (horizontal position)

~~24, 25, 25, 26, 26, 27, 27, 27, 28, 28, 28, 29,~~ [29, 30, 30, 30, 30, 30, (32), 32, 32, 33, 33, 33, 33]

Rebound value (R) = 32

Core testing

An accessory called a core holder is needed for testing core with the L-type Schmidt hammer. The core holder consists of a steel plate that serves as a stand for a vertical V-bar guide for the Schmidt hammer, and on which is attached a semicylindrical cradle large enough to accommodate NX--2 1/2-inch- (6.4-cm-) diameter--cores. The core holder weighs 21.25 pounds (9.7 kg) and serves as a firm base upon which to test core samples (fig. 4). The core holder can be purchased from several rock- and soil-testing equipment distribution companies.

The hammer is held vertically against the V-bar guide for testing core samples. Twenty-five separate readings are taken on the core following this procedure. The sample is rotated approximately 45° for each reading, taking care to offset the core longitudinally between each reading to avoid striking a spot previously tested.

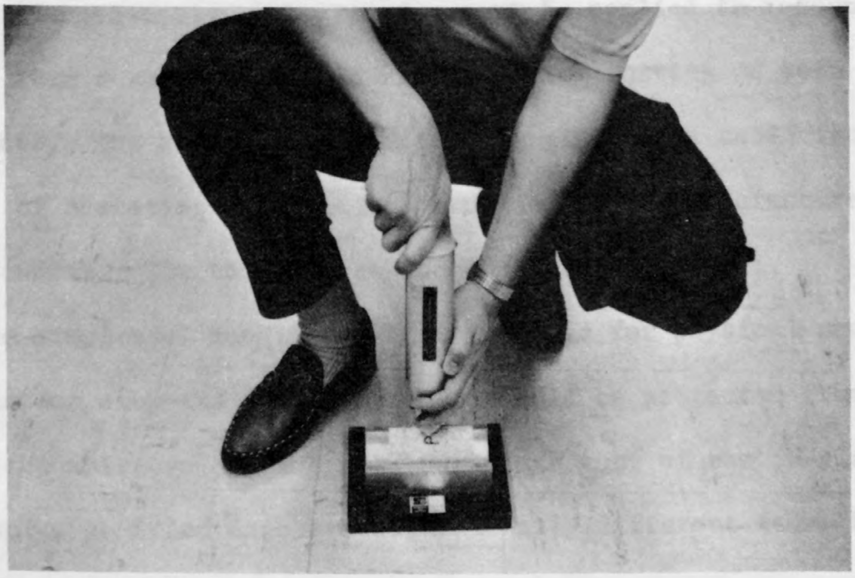


Figure 4.--Method of using the L-type Schmidt hammer and core holder.

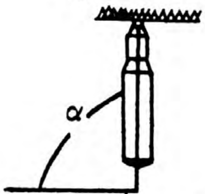
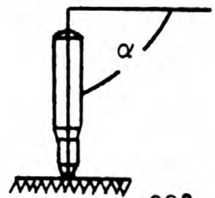
The correlation charts presented in this report are standardized for the L-type Schmidt hammer held in a horizontal position and calibrated to a nominal rebound value of 74 on a 35-pound- (16-kg-) test anvil with a steel hardened surface of Brinell hardness of 500 $\frac{kg}{mm^2}$. Consequently, a correction must be applied to rebound values obtained from a vertically held hammer during testing of core in the core holder. The amount of correction is given in a table from the handbook of operating instructions provided by the manufacturer of the instrument. The table is reproduced here as table 1.

Core samples of zeolitized tuff intended for physical-properties determination with the Schmidt hammer should be protected from drying so that the moisture content will duplicate that of the in-place rock. Test results on dried core are significantly different from those obtained on naturally occurring water-saturated tuff.

Tunnel wallrock testing

Smooth, sound rock that lies behind dried surface slabs and spall sheets is best for testing in-place tuff in tunnels. The slabs and sheets can be removed with a geologic pick prior to testing, and the rock gaged for soundness by tapping with the geologic pick. Scraping and pounding in the immediate area of the test should be avoided so as not to disturb the natural condition of rock that is to be tested. The hammer is placed perpendicular to the vertical rock surface and held as nearly horizontal as possible. Twenty-five

Table 1.--Correction of rebound value for nonhorizontal impacts (with an L-type Schmidt hammer). Adapted from Eisenhut, 1960, Operating instructions--Concrete test hammer, Type L.

Uncorrected rebound value	Corrections for angle of inclination			
	upward (+) 		downward (-) 	
	+90°	+45°	-45°	-90°
10			+2.4	+3.2
20	-5.4	-3.5	+2.5	+3.4
30	-4.7	-3.1	+2.3	+3.1
40	-3.9	-2.6	+2.0	+2.7
50	-3.1	-2.1	+1.6	+2.2
60	-2.3	-1.6	+1.3	+1.7

Example:

If a test taken at -90° has a median rebound value of 20, the horizontal equivalent will be 20 +3.4 = 23.4. This can be rounded off to 23.

rebound numbers are taken in this manner. Rebound values calculated from hammer numbers obtained while impacting at an angle other than horizontal require a correction factor that converts the values to the horizontal standard (table 1). Repeated impacts on the same spot should be avoided because it can result in spuriously high readings in water-saturated tuff. This probably is due to densification of the porous tuff, expulsion of pore water, and lowering of pore pressure which thereby increase the effective stress. All these factors result in a local strengthening of the rock at the impact point.

DERIVATION OF CORRELATION BETWEEN REBOUND VALUES AND PHYSICAL PROPERTIES OF ZEOLITIZED TUFF

Bedded tuff beneath Rainier Mesa in the Nevada Test Site is the medium in which there has been extensive tunneling. Schmidt hammer tests and laboratory analyses of the rocks from the tunnels provided the basis for this study. The bedded tuff consists predominantly of pumiceous tuff that has undergone zeolitic alteration without appreciable change of the original rock texture. The rock commonly contains abundant quartz and feldspar crystals and volcanic rock fragments such as rhyolite, welded tuff, and chert, which range in diameter from 1 mm to 2.5 cm. All the rock at depths surrounding the major tunnel complexes in Rainier Mesa is water saturated. Tests to date in the existing tunnels show water saturations ranging from 80 to 100 percent. The fluid and gas permeabilities of unfractured rock, however, are very low even though the porosity is high.

The bedded tuff beneath Rainier Mesa can be qualitatively described as consisting of alternating layers of relatively harder and softer rocks. Thus the overall strength and other properties of tuffs may be controlled regionally by stratigraphy and locally by structures such as faults and joints.

The samples that were collected for this study were taken from the U12n, U12e, and U12g tunnel complexes, which represent an underground sampling area of 1.8 miles by 0.75 mile (2.9 by 1.2 km) (fig. 5).

Samples for determining the relation between rebound values taken on tunnel walls and the properties of the tuff were obtained from 4-feet by 6-inch (120 by 15.5 cm) cores drilled from the area tested. Schmidt hammer tests were also made on these cores to insure that the rebound values calculated from the tunnel walls matched those taken on the cores drilled from the same wall area. The only instances where differences existed between cores and wallrock were in those localities where the outer layer of wallrock had dried out. Removing the slab of dried wallrock and retesting the exposed fresh surface brought about matching core- and wallrock-rebound values. The 6-inch cores were then wrapped at once in aluminum foil and sealed by dipping in beeswax so as to insure their as-received-state water content. Additional data were obtained in the same manner from NX-size cores drilled along proposed tunnel alinements for exploratory purposes.

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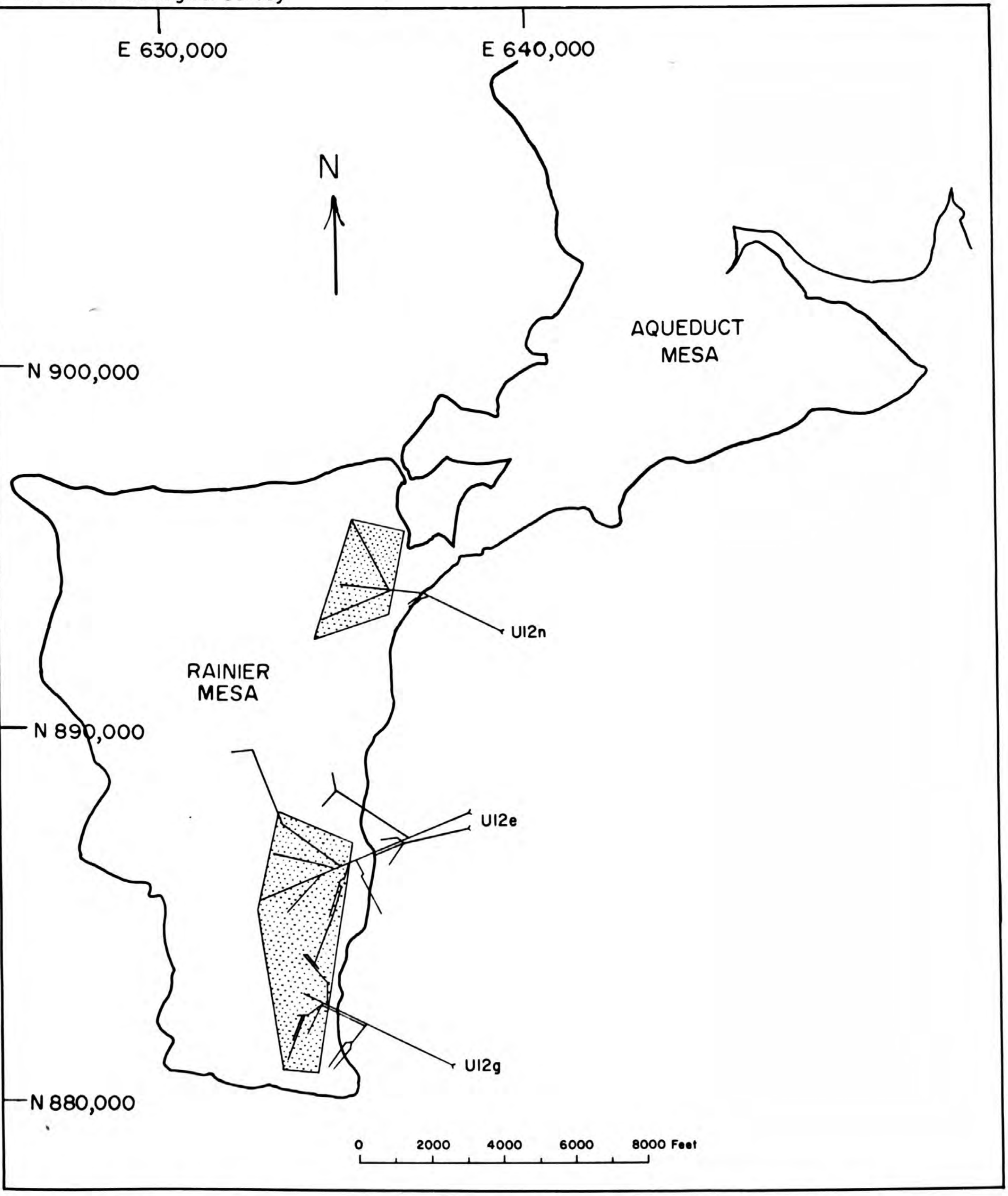

Figure 5--Map showing tunnel areas included in Schmidt hammer testing of zeolitized tuff, Rainier Mesa, Nevada Test Site. Stippled areas are those in which tests were performed.

Sections from all cores were sent to the following engineering testing laboratories for physical-properties determinations: U.S. Geological Survey, Denver, Colorado; U.S. Corps of Engineers, Jackson, Mississippi; and Nevada Testing Laboratories, Ltd., Las Vegas, Nevada. This procedure permitted independent test results to be obtained on all the cores for comparison with the test results from the other two laboratories, and eliminated any bias that might have resulted from techniques followed by any single laboratory. There were no significant differences in property values of the tuff samples tested by the three laboratories.

When possible, all the following tests were conducted on the core samples in their natural state.

1. Natural-state density
2. Unconfined compressive strength
3. Static Young's modulus
4. Static shear modulus
5. Static bulk modulus
6. Static Poisson's ratio
7. Compressional velocity
8. Shear velocity
9. Dynamic Young's modulus
10. Dynamic shear modulus
11. Dynamic bulk modulus
12. Dynamic Poisson's ratio
13. Dry bulk density
14. Porosity
15. Schmidt hammer rebound values

The physical properties determined in the laboratory and the Schmidt hammer rebound values obtained in the tunnels and from cores were related by a least-squares regression analysis. The results of the regression program were graphed and are presented as figures 6-19. The correlations are for Schmidt hammer values taken from the horizontal test position and calibrated at a rebound value of 74. Hence, when using the graphs, any rebound values not obtained from a horizontal hammer orientation must be converted to horizontal values by means of table 1.

DISCUSSION OF RESULTS

Table 2 is a list of correlation coefficients that indicate the degree of correlation between the L-type Schmidt hammer rebound values and the physical properties of water-saturated zeolitized tuff. In 11 out of 13 tests the correlation coefficient is equal to or greater than 0.70 and in 7 out of 13 tests it is greater than 0.80. These high values show that good statistical agreement exists between Schmidt hammer values and most of the physical properties tested.

Table 3 shows the reproducibility test of Schmidt hammer rebound values conducted on 14 water-saturated zeolitized tuff samples. Two sets of 25 rebound numbers were obtained from two separate tests performed on each of 14 tuff samples. The rebound values shown on table 3 are the median value of the upper 13 rebound numbers.

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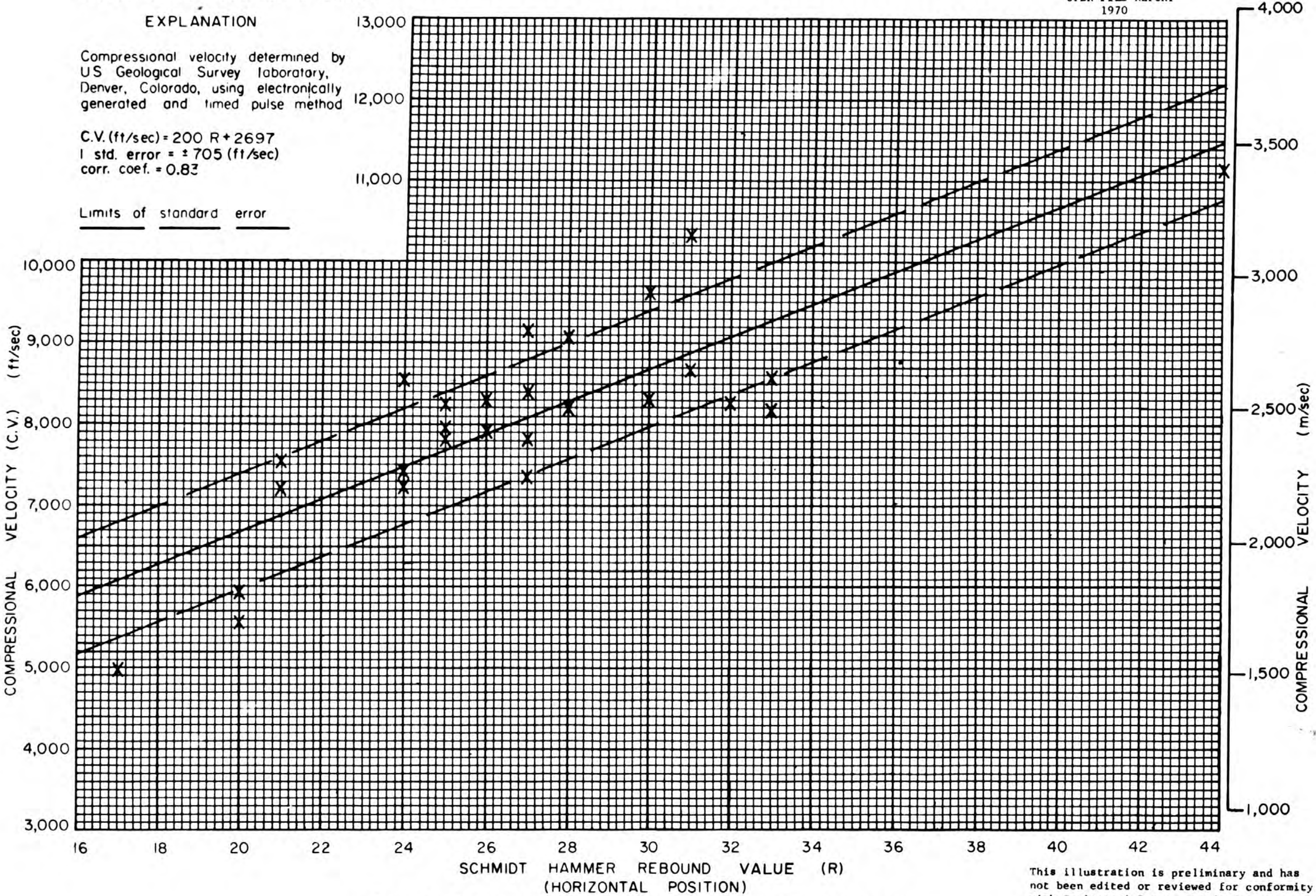

Figure 6.-- Relation between compressional velocity and rebound value.

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EXPLANATION

Shear velocity determined by U. S. Geological Survey laboratory, Denver, Colorado, using electronically generated and timed pulse method

S.V. (ft/sec) = 141 R + 788
1 std error = ± 441 (ft/sec)
corr. coef. = 0.85

Limits of standard error

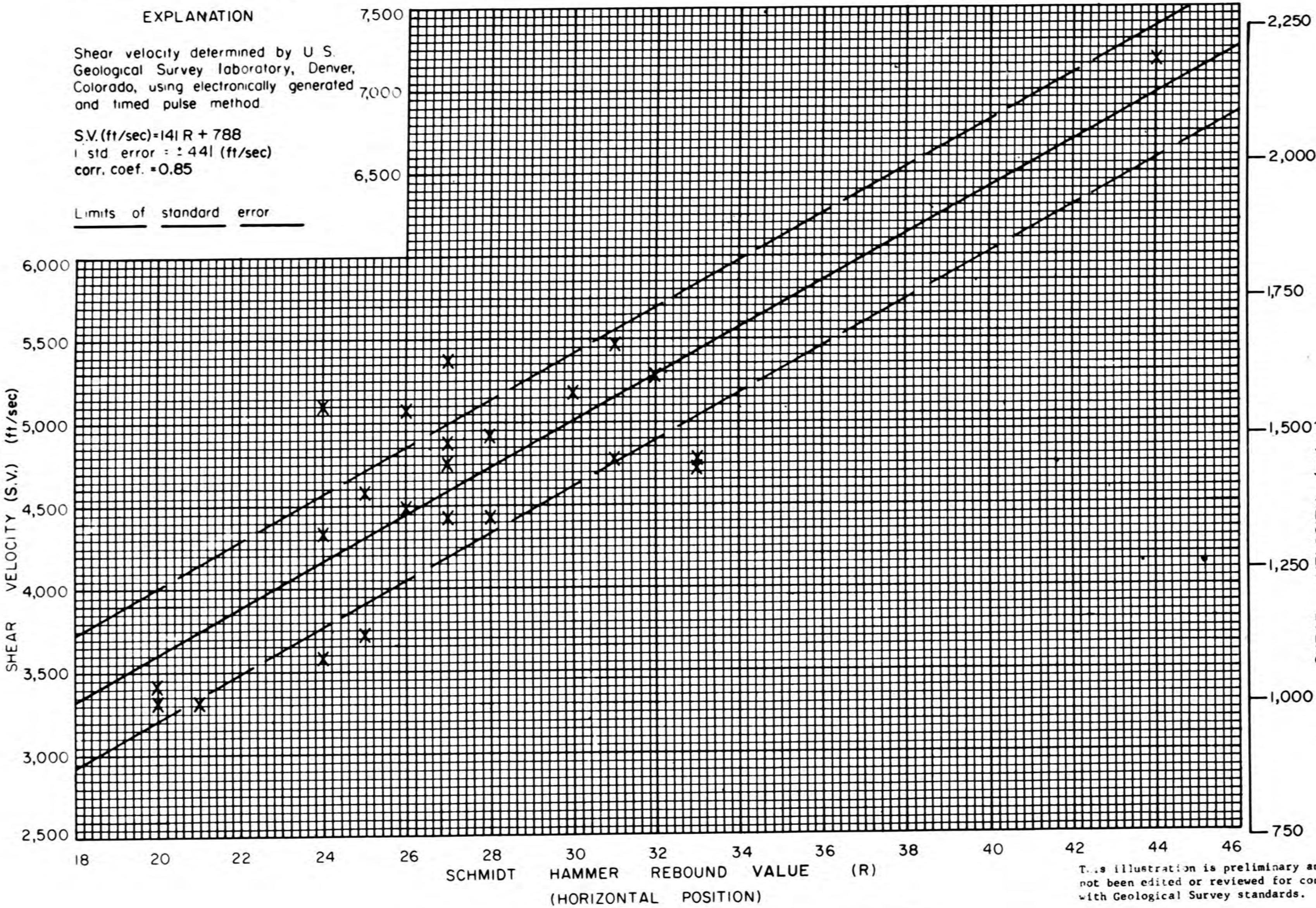

Figure 7. -- Relation between shear velocity and rebound value.

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EXPLANATION

Dynamic Young's modulus determined by U S Geological Survey laboratory, Denver, Colorado, using electronically generated and timed pulse method

Y.M. (10^6 psi) = 0.087 R − 0.994
1 std error = ±0.22 (10^6 psi)
corr. coef. = 0.89

Limits of standard error

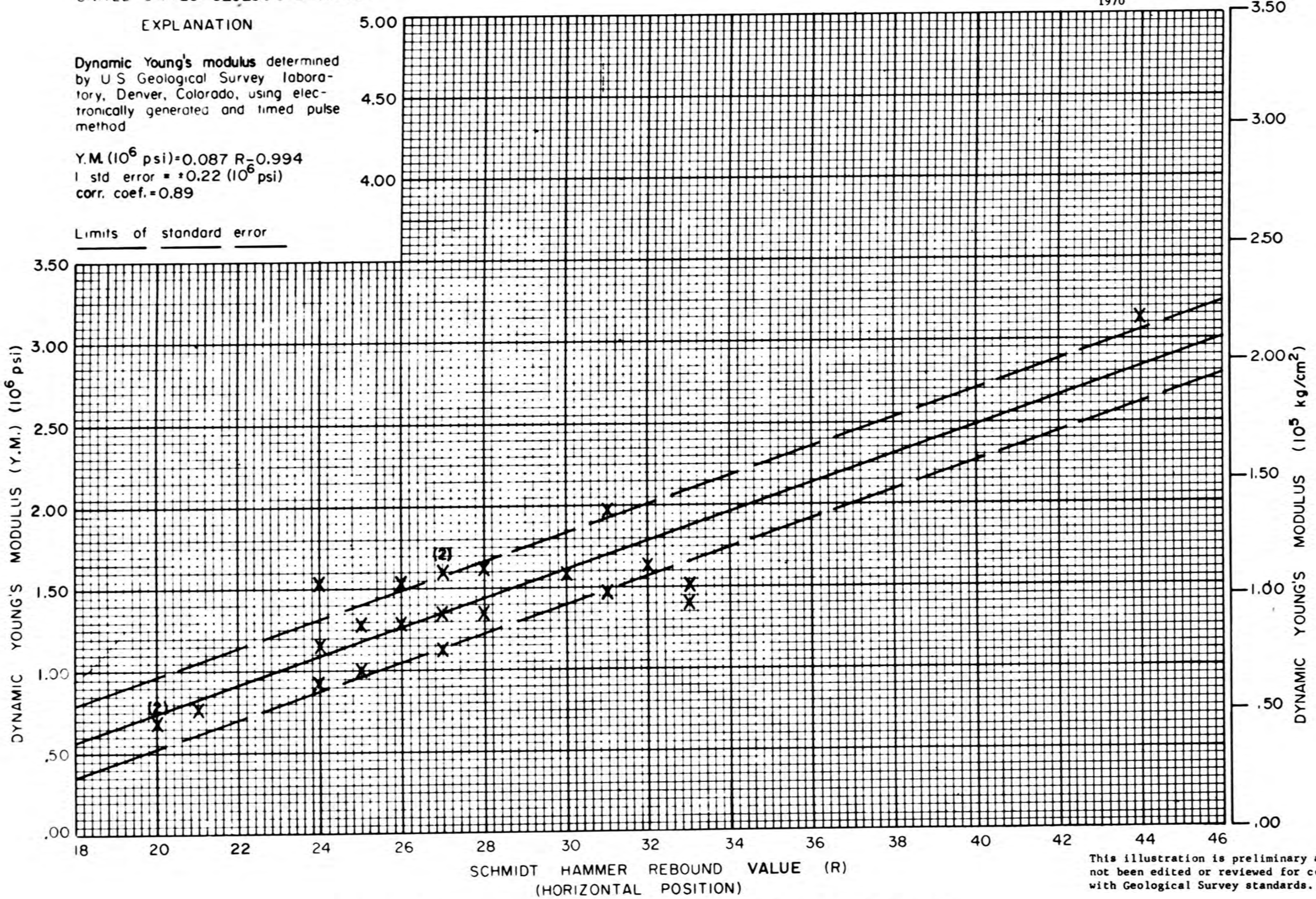

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Figure 8.--Relation between dynamic Young's modulus and rebound value.

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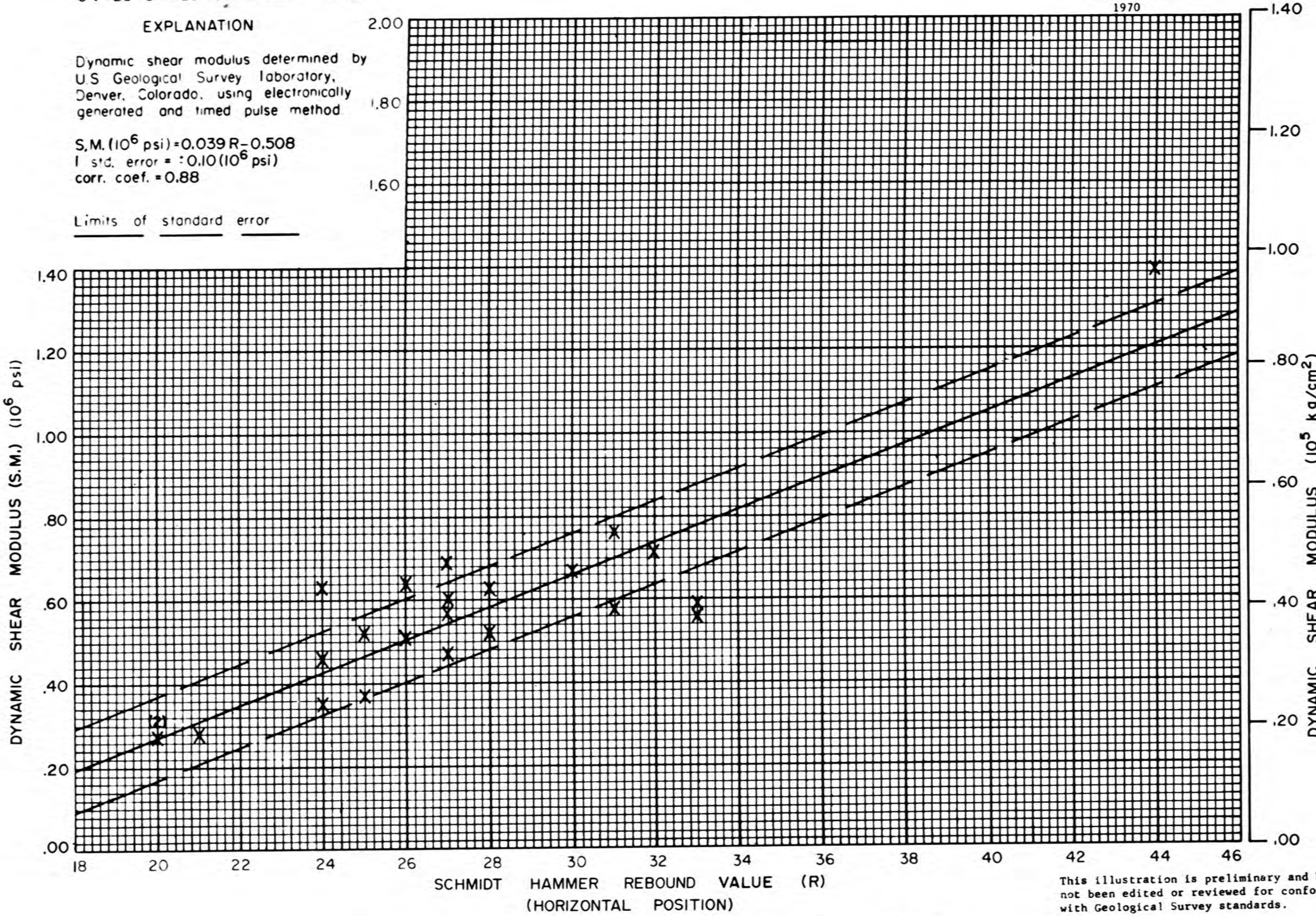

Figure 9.--Relation between dynamic shear modulus and rebound value.

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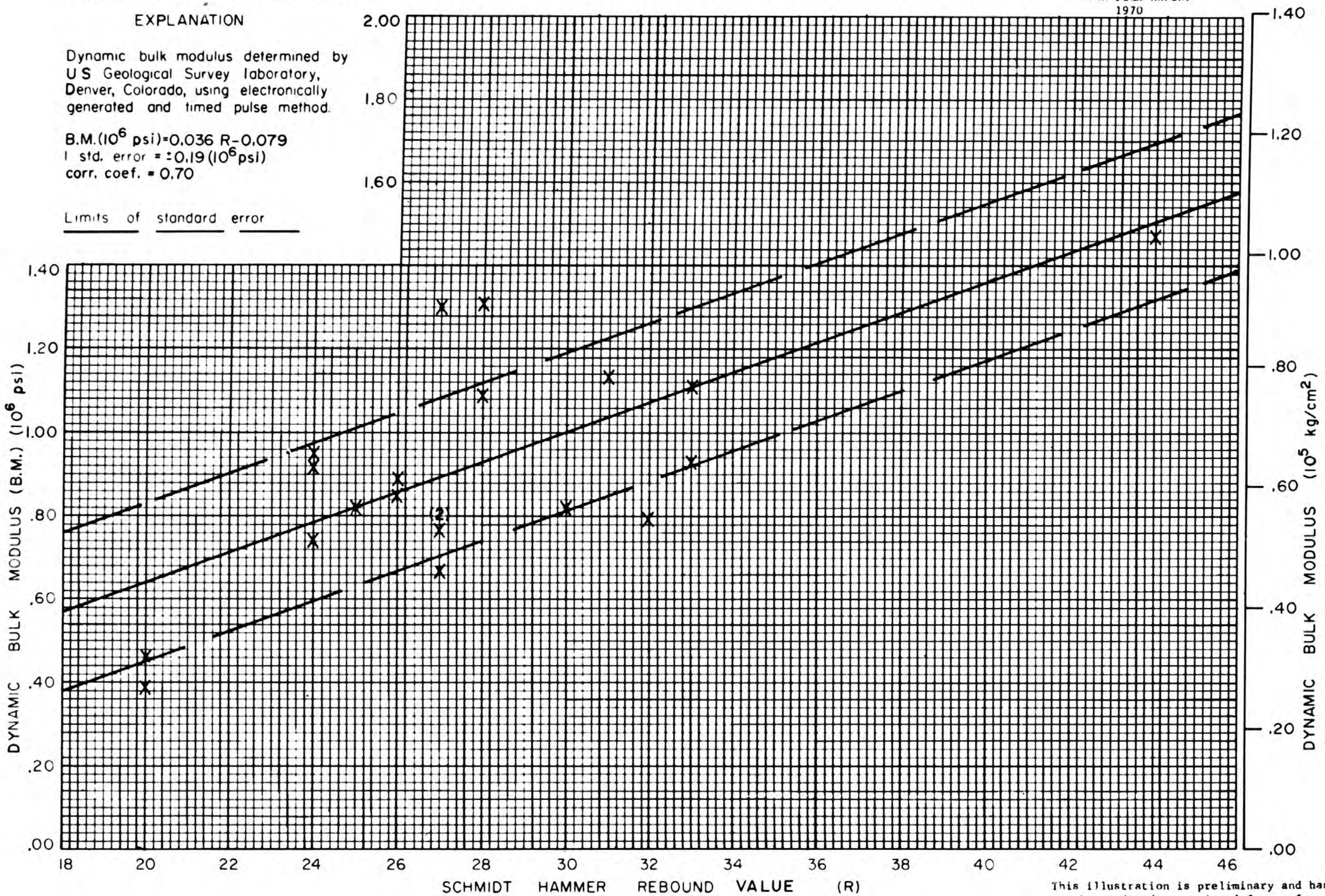

Figure 10.--Relation between dynamic bulk modulus and rebound value.

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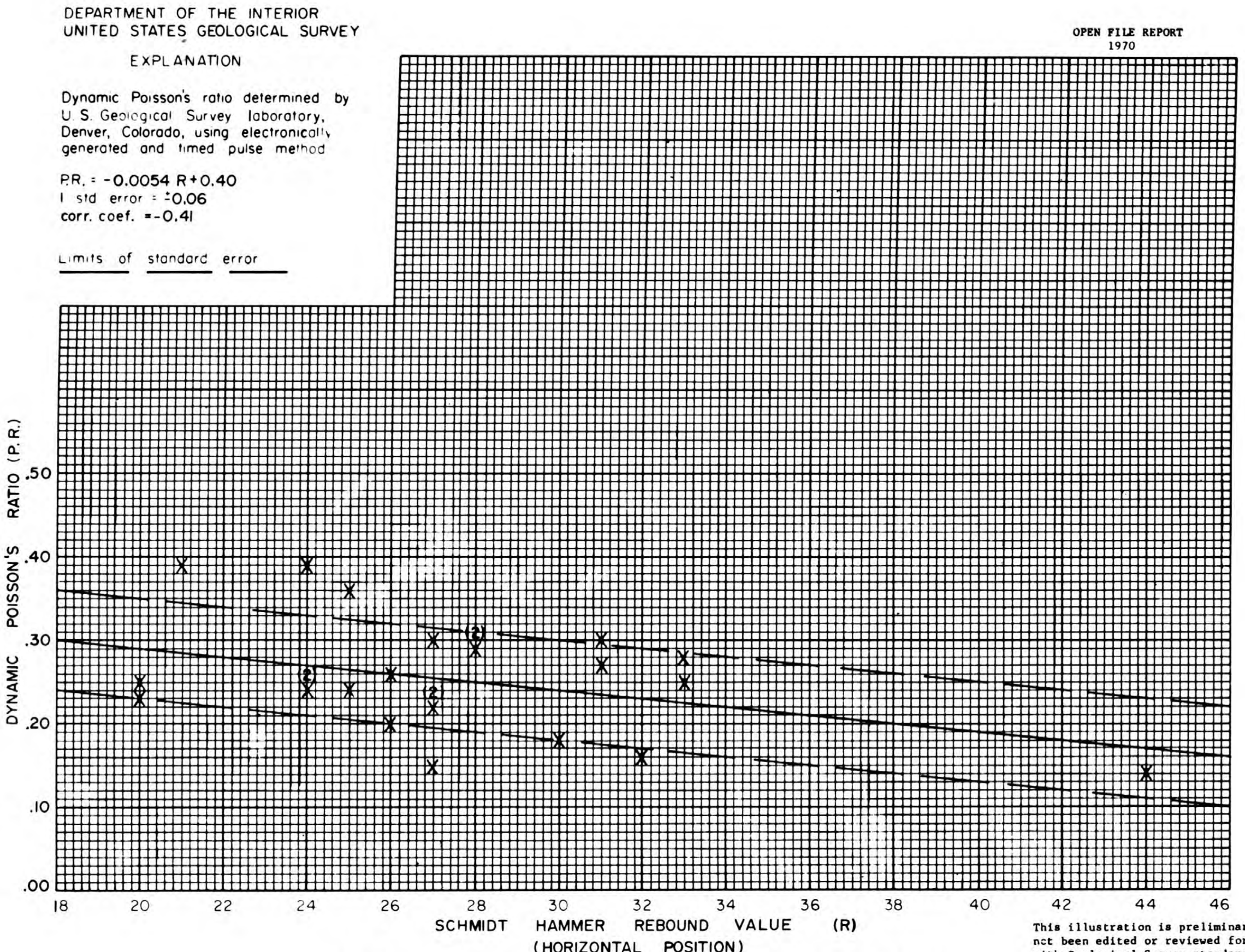

Figure 11.--Relation between dynamic Poisson's ratio and rebound value.

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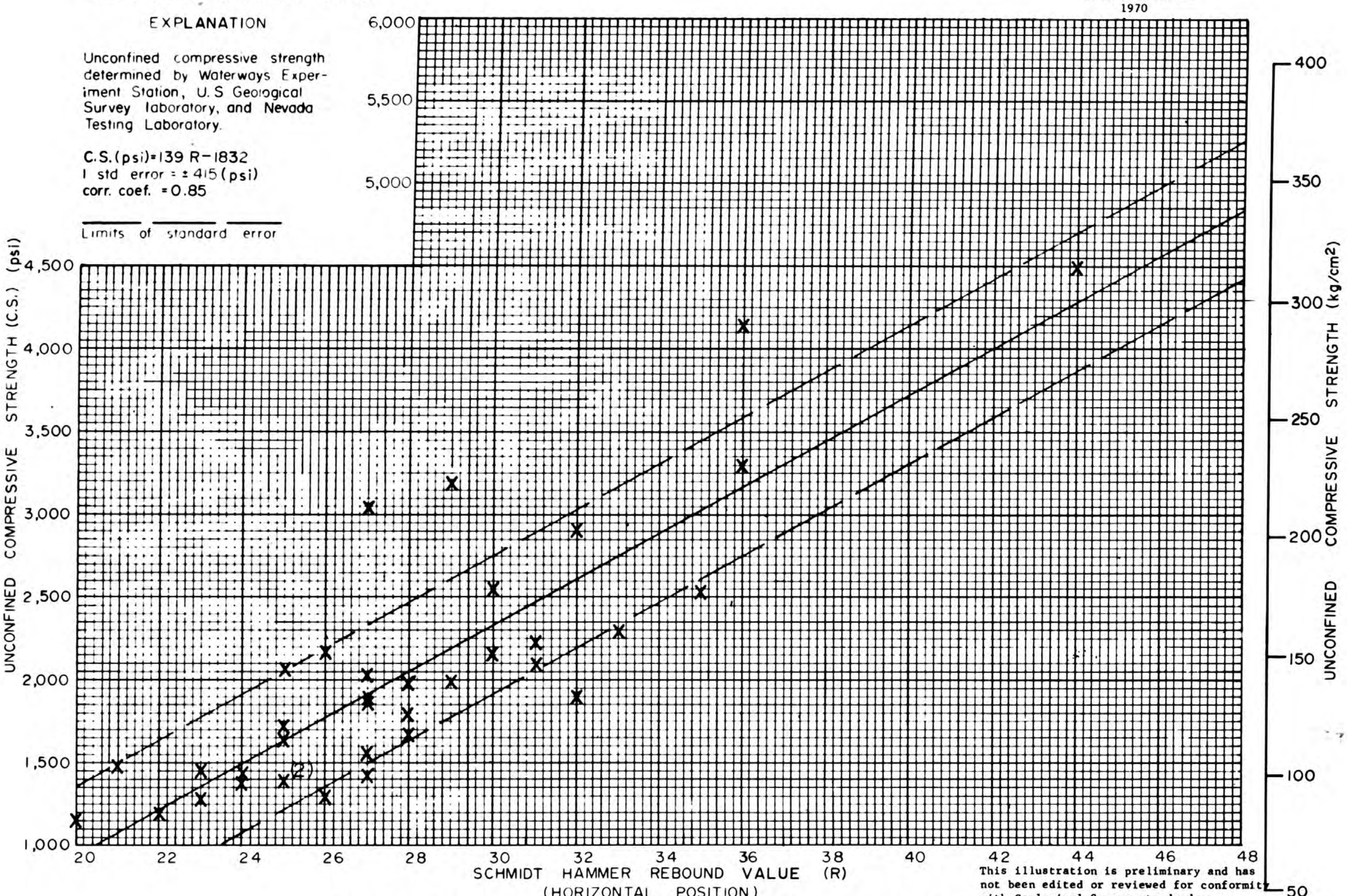

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Figure 12.--Relation between unconfined compressive strength and rebound value.

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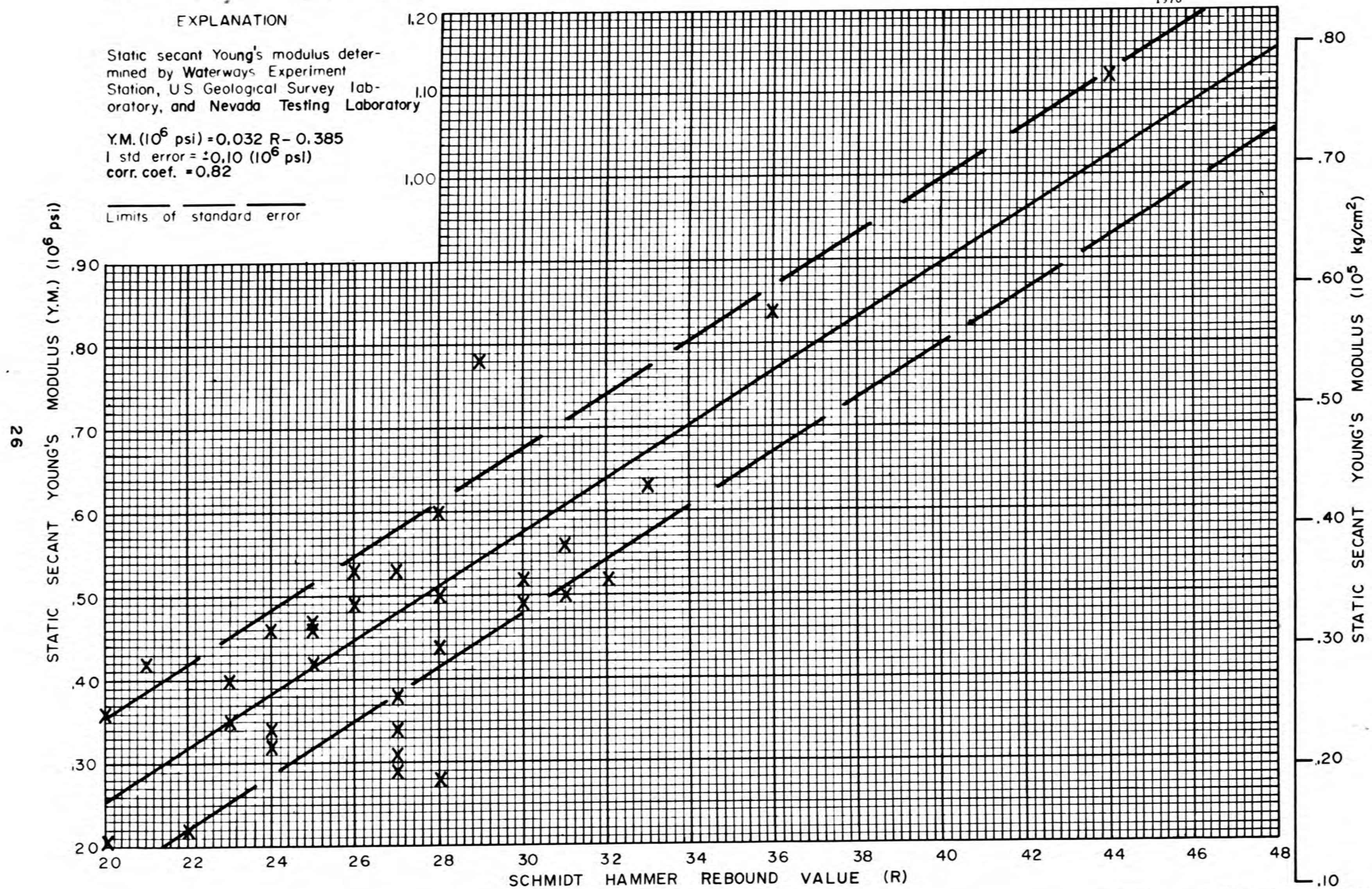

Figure 13.--Relation between static secant Young's modulus and rebound value.

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EXPLANATION

Static shear modulus determined by Waterways Experiment Station, U S Geological Survey laboratory, and Nevada Testing Laboratory.

S.M. (10^6 psi) = 0.014 R - 0.172
1 std error = ± 0.05 (10^6 psi)
corr. coef. = 0.81

Limits of standard error

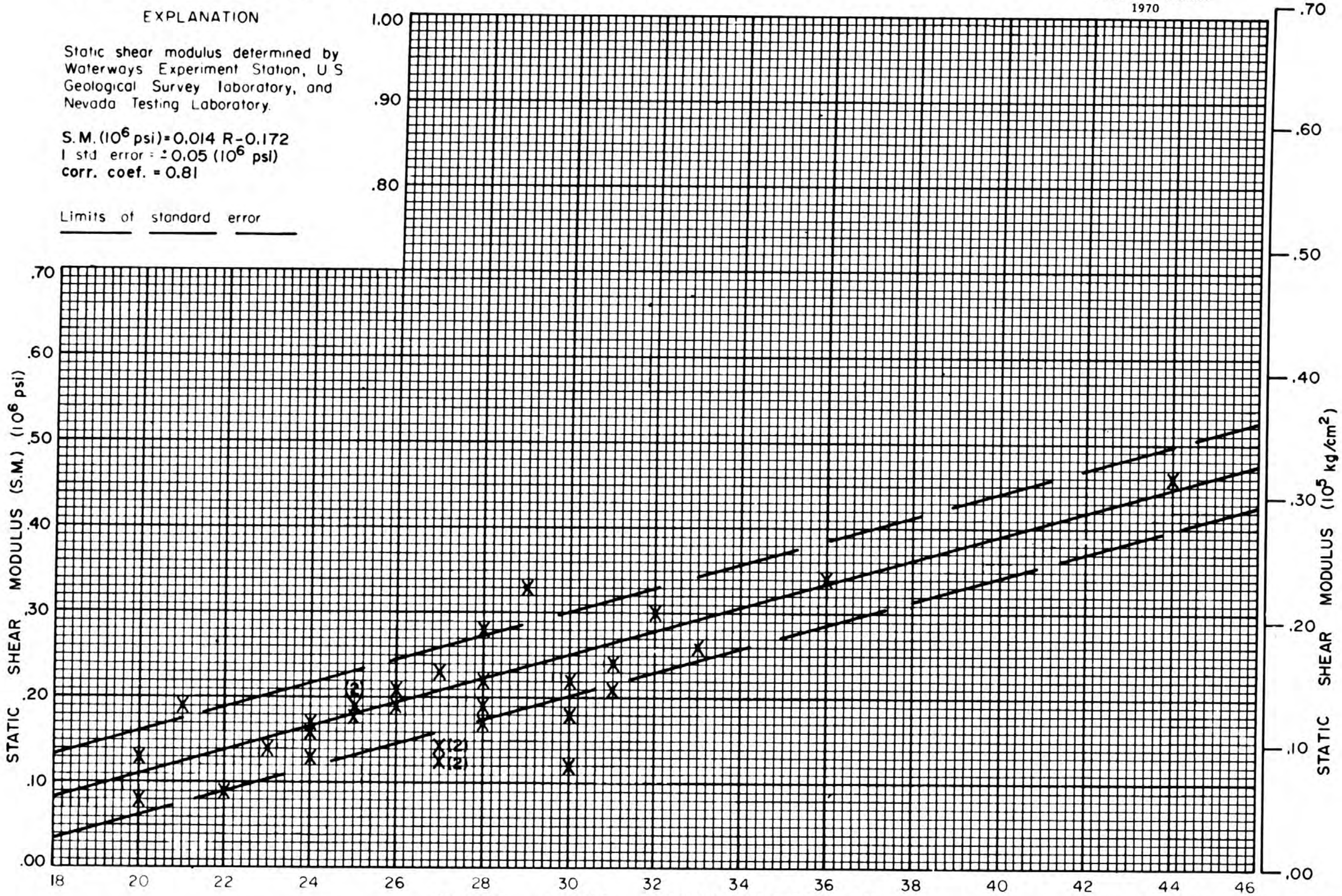

Figure 14.--Relation between static shear modulus and rebound value

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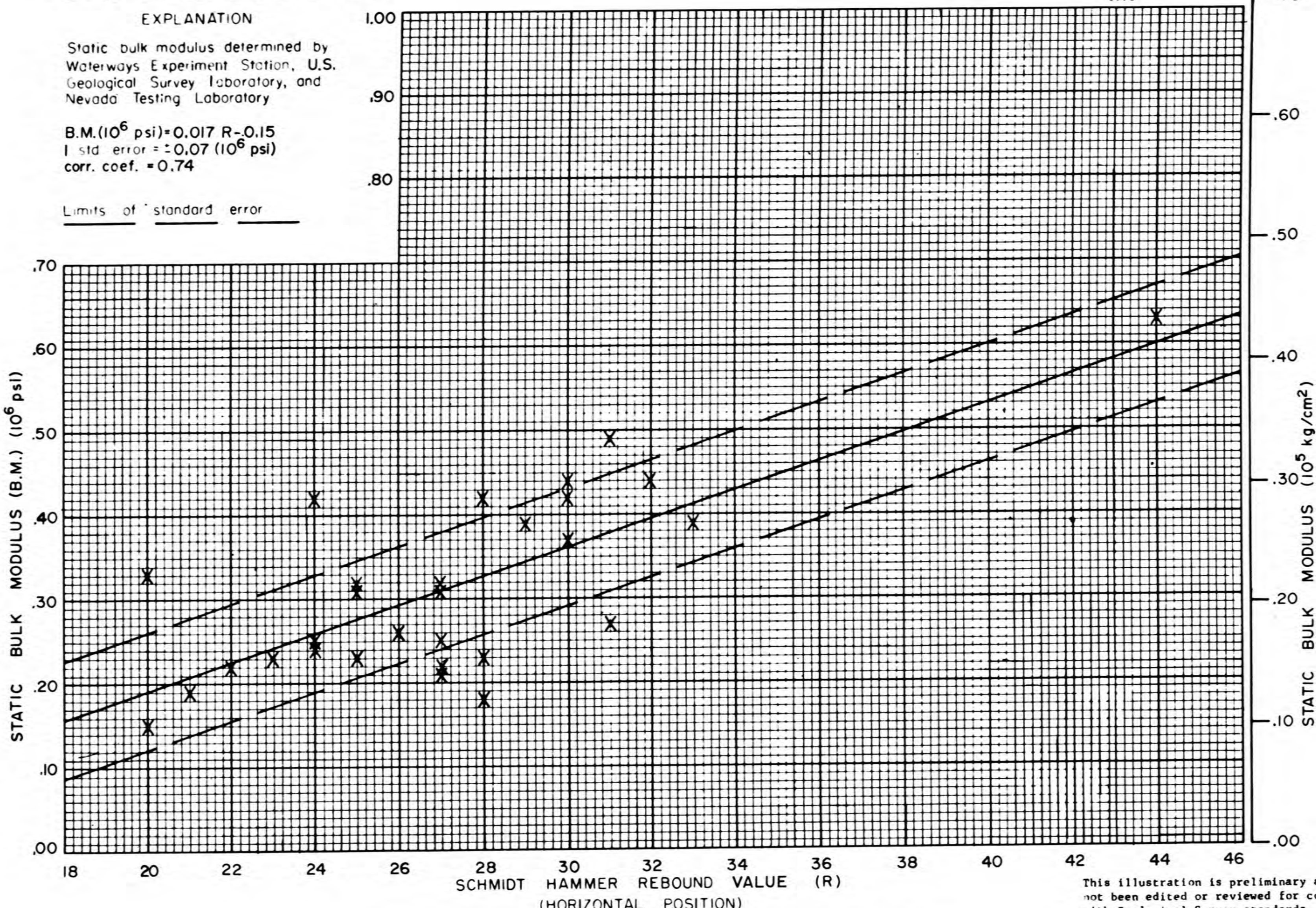

Figure 15.--Relation between static bulk modulus and rebound value.

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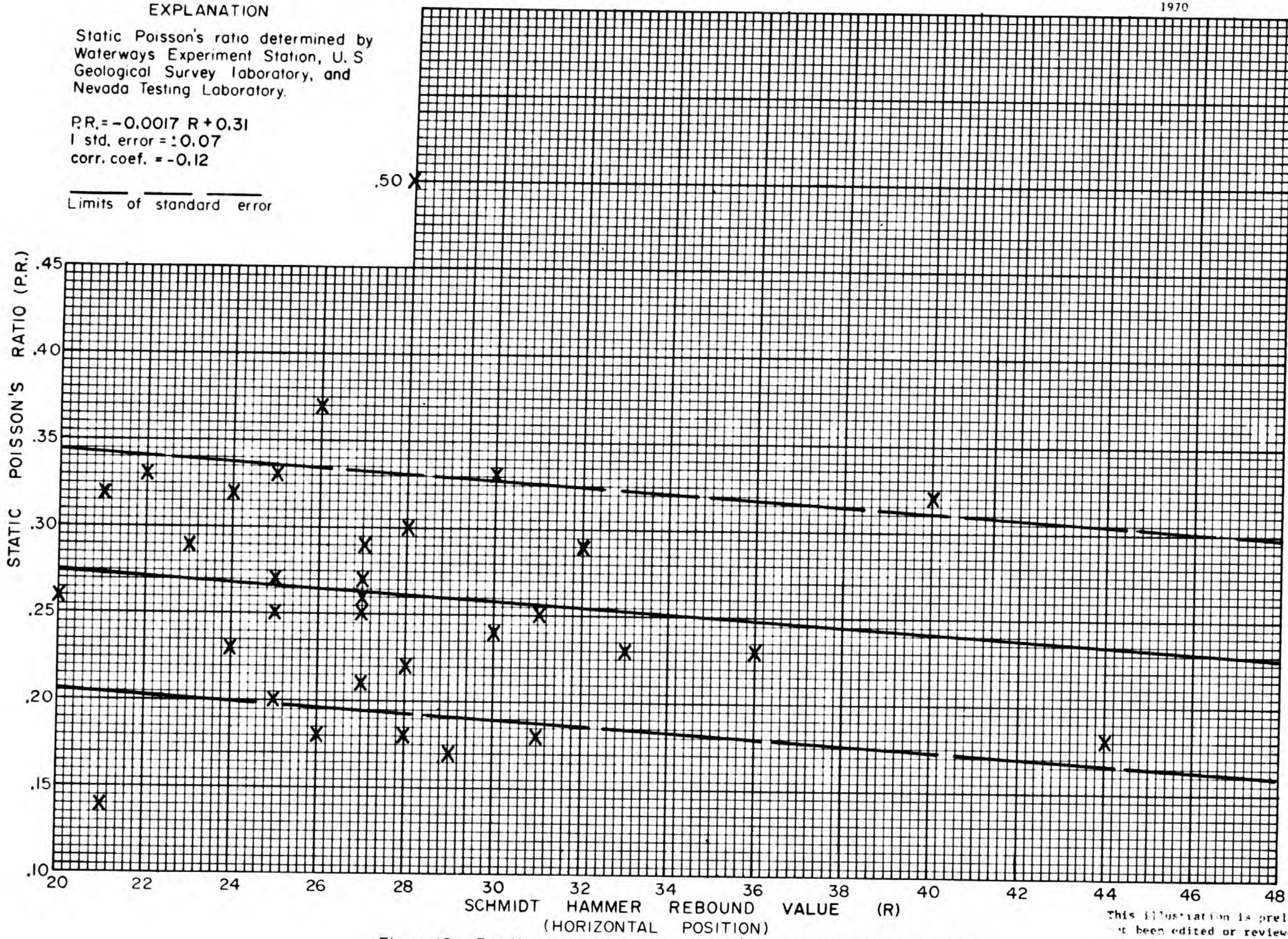

Figure 16.--Relation between static Poisson's ratio and rebound value.

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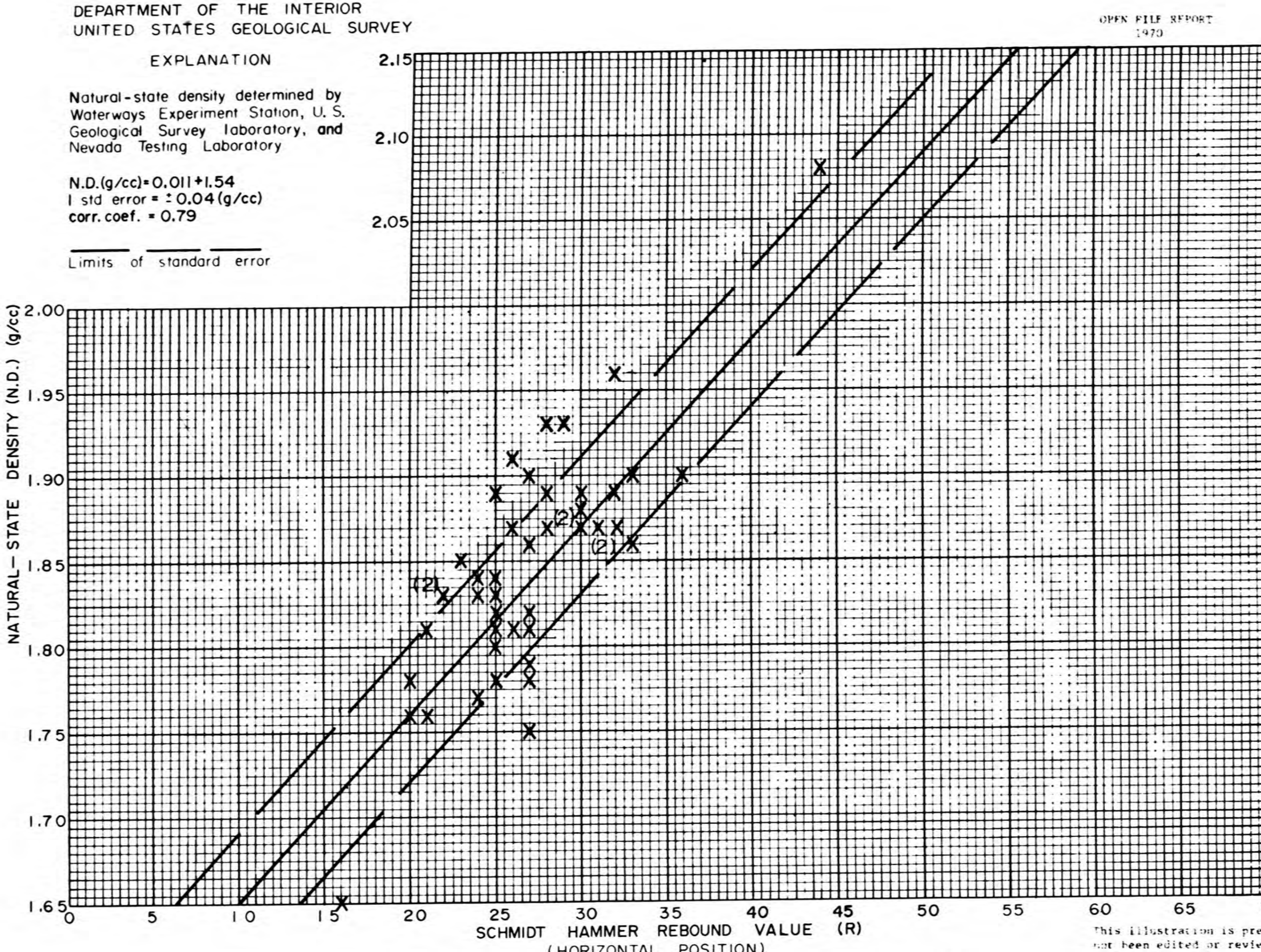

Figure 17.--Relation between natural-state density and rebound value.

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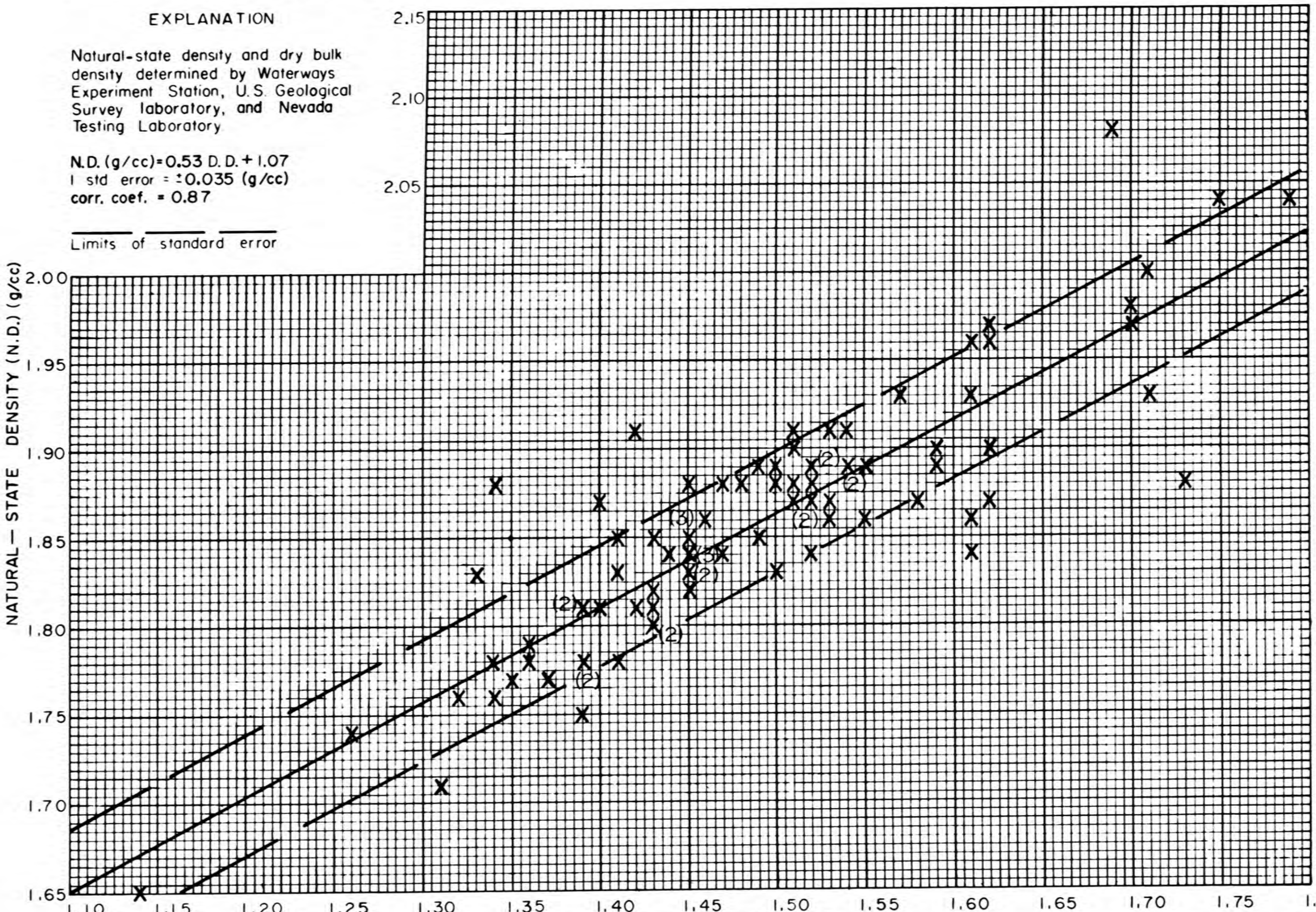

Figure 18.--Relation between natural-state density and dry bulk density

This illustration is preliminary and has not been edited or reviewed for conformity with Geological Survey standards.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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EXPLANATION

Porosity determined by Waterways Experiment Station, U.S. Geological Survey laboratory and Nevada Testing Laboratory.

P. = - 0.49 R + 51
I std. error = ± 2.8(%)
corr. coef. = - 0.70

Limits of standard error

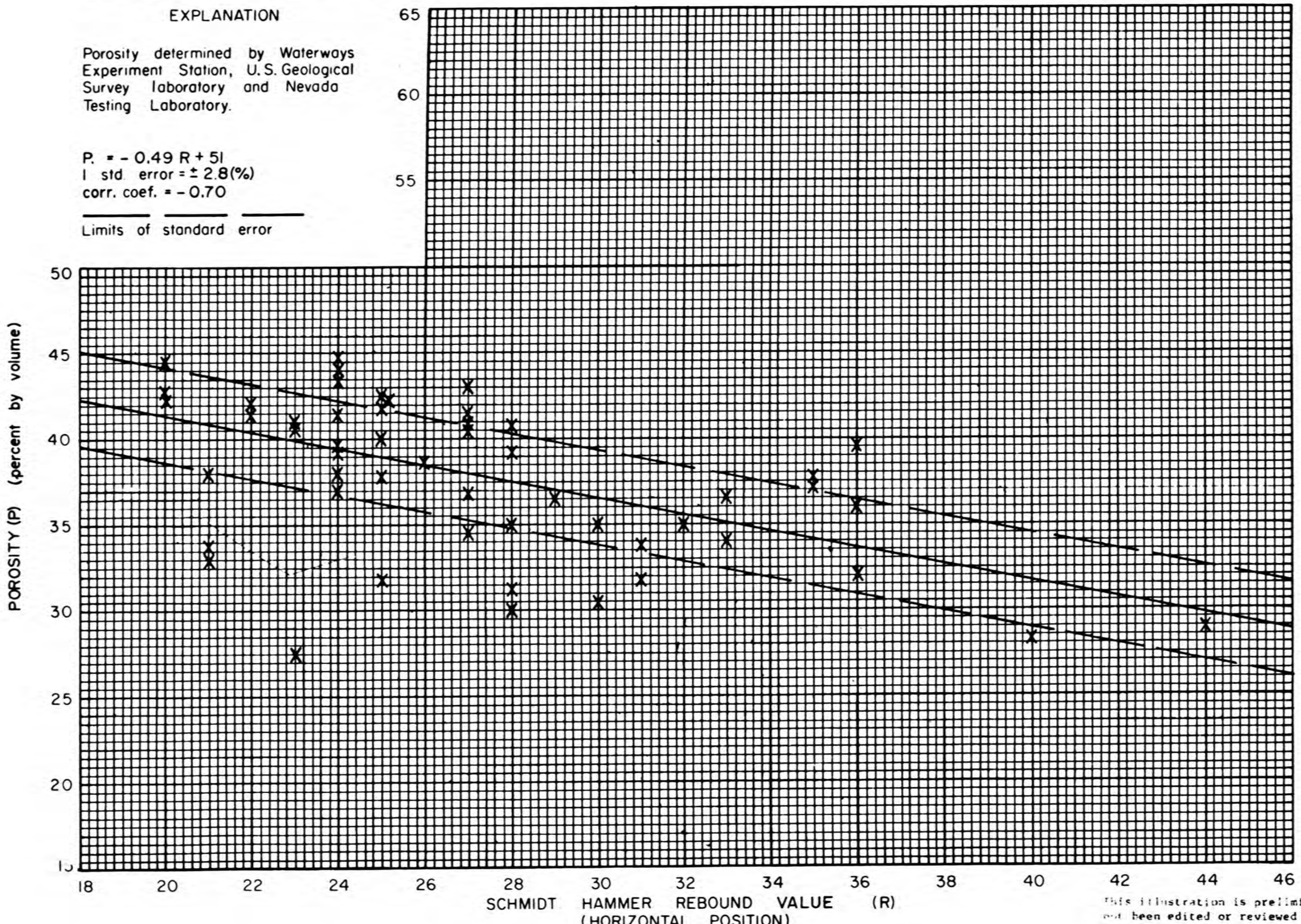

Figure 19.--Relation between porosity and rebound value.

Table 2.--Correlation coefficients for rebound values and physical properties of water-saturated zeolitized tuff

Dynamic tests	Coefficient of correlation
Compressional velocity	0.83
Shear velocity	.85
Young's modulus	.89
Shear modulus	.88
Bulk modulus	.70
Poisson's ratio	-.41

Static tests	
Unconfined compressive strength	.85
Secant Young's modulus	.82
Shear modulus	.81
Bulk modulus	.74
Poisson's ratio	-.12
Density, natural-state	.79
Porosity	-.70

Table 3.--Reproducibility of L-type Schmidt hammer rebound values. Two individual tests were made on each of 14 samples of water-saturated zeolitized tuff

Sample number	Schmidt hammer rebound value	
	First run	Second run
1	23	22
2	24	23
3	24	24
4	25	25
5	26	24
6	28	28
7	28	28
8	28	29
9	28	30
10	28	30
11	28	31
12	30	31
13	32	34
14	37	36

APPLICATION OF THE L-TYPE SCHMIDT HAMMER FOR TESTING ZEOLITIZED TUFF IN TUNNELS AT THE NEVADA TEST SITE

The L-type Schmidt hammer can be used to obtain physical properties of zeolitized tuff from horizontal and vertical exploratory cores immediately upon their removal from the core barrel.

In tunnels, physical-property profiles along the tunnel alinement can be made by testing at specified intervals. Detailed horizontal and vertical surveys of critical zones, such as keyways and instrument stations, can be accomplished quickly. Postshot surveys of wallrock can be done easily so as to compare rock physical properties with preshot values. The Schmidt hammer can also be used to check the strength of any concrete structures in the tunnels. The manufacturer's instructions show concrete-compressive strength graphs and correction table for nonhorizontal impacts. Outcrops can be checked in connnection with site-selection studies in tuffaceous rock. (Graphs for dried core have been published by Deere and Miller (1966) and may be applicable for nonwater-bearing tuff.) If fresh, water-saturated surfaces can be found, the graphs in this report can be used for direct conversion to physical properties. Many other applications are possible whenever physical-properties data are needed for water-saturated zeolitized tuff.

CONCLUSIONS

The L-type Schmidt hammer is a useful and reliable field tool for determining physical properties of zeolitized tuff in its natural state. The hammer can be used on core samples, outcrops, and tunnel walls. Immediate interpretation of the hammer tests in terms of derived values of compressive strength, Young's modulus, and other moduli can be made by referring to the correlation diagrams included in this report, which relate Schmidt hammer rebound values to natural-state density and to dynamic and static physical properties.

The correlation diagrams showing the relation between the L-type Schmidt hammer rebound values and physical properties are reliable only insofar as (1) they are applied to zeolitized tuffs of the type found under Rainier Mesa at the Nevada Test Site in their natural (saturated) state, and (2) the tests are performed in the manner described under "Procedure." The graphs are valid only for the L-type model. Other models of the Schmidt hammer are manufactured and are classified according to the amount of impact energy produced by the spring.

REFERENCE CITED

Deere, D. U., and Miller, R. P., 1966, Engineering classification and index properties for intact rock: Air Force Weapons Lab. Tech. Rept. No. AFWL-TR-65-116, 300 p.