LBL-3646

STATUS OF THE GEODOSE PROJECT*

Harold A. Wollenberg and Joan Fi patrick

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

The evaluation of the impact of man upon the na ral gamma-radiation environment requires a clear understanding of the distribution and abundance of the natural radioelements in rocks and soils. The GEODOSE Project is an attempt to characterize rock and soil types by their natural gamma-ray exposure rates. The world's geochemical literature is being searched for data on K, U, and Th contents of earth materials, and these data are categorized by rock type, based on standard petrologic classifications. A data bank is being assembled, presently incorporating radioelement information on the igneous rocks. The data are treated tc produce computer plots of histograms of K, U, Th contents, calculated gamma-ray exposure rates, and radiogenic heat production for given rock types. Accompanying these plots will be means, standard deviations, and ranges

*Work performed under the auspices of the U. S. Energy Research and Development Administration.

of the parameters. Initial processing of data for igneous rocks indicates that alkaline and peralkaline terranes have generally the highest gamma-ray exposure rates of the igneous rocks, and suggests that alkaline and peralkaline rocks are probably associated with most of the broad areas of highest natural radioactivity.

Terrestrial sources of the natural gamma-radiation environment are the radioelements, ^{238}U, ^{232}Th, their decay products, and ^{40}K. Within regions of given altitude and geomagnetic latitude, the varying gamma-ray field from these elements in rocks and soil is superimposed on a nearly constant gamma field from cosmic radiation. Typically, the cosmic-ray induced field compris 1/4 to 1/3 the total; the rest is from the radioelements. Thus, major spatial variations in the natural gamma radiation are caused by variations in the abundance and distribution of U, Th, and K.

There is appreciable data, primarily in the literature of geochemistry, describing the distribution and abundance of these elements. A survey of this literature, from all the world's countries, is underway which will ultimately result in the cataloging and characterization of natural radioelement contents and their corresponding rock and soil types. A data bank is being assembled, presently incorporating radioelement information on the igneous rocks. The formulas of Beck and dePlanque (1968) applied to the U, Th, and K contents of reported rock types, yield gamma-ray exposure rate values (Wollenberg and Smith, 1972). The resulting correlations are then expressed as histograms of K, U, Th contents and calculated gamma-ray exposure rates for given rock types. Data listings include radioelement content, exposure rates, and citations of the source of information.

One step in this study deals with bedrock materials, from which all soils are derived, and about whose radioelement contents there is a fair amount of data. Based on experience we can categorize rock types petrologically in groups which have appreciably different mean radioelement contents:

A. Igneous Rocks: the detailed breakdown of igneous rock categories is shown on Table 1.

B. Sedimentary rocks will be classified in the following manner:

1. Clastics: sandstone, shale, conglomerate, clays, and beach sands.

2. Non-clastics: carbonates, sulfates, cherts.

C. Metamorphic rocks will be classified broadly according to their igneous or sedimentary parentage:

1. Metavolcanic: alkaline, felsic, andesitic, basaltic.

2. Metasedimentary: quartzite, slate, phyllite, schist, and higher grade metasedimentary rocks.

Another facet of this study will be categorization of the gamma radioactivity of soils. In many cases this is more difficult to accomplish than the synthesis of bedrock exposure rates, because the components which make up soils may be transported long distances from their parent rocks, undergoing profound chemical changes enroute to depositional areas. However, in many regions soils are residual, derived directly from weathering in-place of rock. Examples are lateritic soils, developed

TABLE 1

GEODOSE CATEGORIES, IGNEOUS ROCKS

ACID INTRUSIVE: Aplite, Pegmatite, Granite, Adamellite, Granodiorite.

ACID EXTRUSIVE: Rhyolite, Dacite, Latite.

INTERMEDIATE INTRUSIVE: Quartz Diorite, Tonalite, Diorite.

INTERMEDIATE EXTRUSIVE: Andesite.

BASIC INTRUSIVE: Gabbro, Anorthosite, some Pyroxenite.

BASIC EXTRUSIVE: Basalt, Spilite.

ULTRABASIC: Peridotite, Dunite, Serpentinite, some Pyroxenite.

ALKALI-FELDSPATHOIDAL INTRUSIVE: Syenite, Nepheline-Syenite, Monzonite, Alkali Gabbro.

ALKALI-FELDSPATHOIDAL INTERMEDIATE EXTRUSIVE: Keratophyre, Trachyte, Phonolite.

ALKALI-FELDSPATHOIDAL BASIC EXTRUSIVE: Nephelinite, Leucitite and Melilite Basalts.

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in tropical regions. The chemistry, especially the radioelement content, of these residual soils reflects the character of their parent material. Because of the difficulty of dealing with transported soils, we shall restrict this phase of the study to the synthesis of radioelement data from bedrock terranes and their residual or closely derived soils; residual soils can be categorized according to their bedrock parentage. In addition, we shall include the fairly extensive radioelement data of beach sand deposits. It is doubtful whether sufficient data exists on glacial till or loess; however, we solicit any available radioelement information on glacial materials for categorization at a future time.

As an example of the format of presentation, histograms of gamma-ray exposure rates for each radioelement, and total exposure rates of acidic[a] igneous rocks are illustrated on Figures 1 through 4. Included on the plots are arithmetic means and their standard deviations. The histograms for U and Th (Figures 1 and 2) indicate log-normal distributions. The broad range in exposure rates for this rock type are shown on Figure 4; the high values ($>15 - 20\ \mu Rh^{-1}$) include data from granitic rocks of the Front Range of Colorado, an acknowledged area of high radioelement contents (Phair and Gottfried, 1964).

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[a] The terms acidic and basic in this context are not used in the sense of pH, but are descriptive of the abundance of silicic acid; rocks highest in silica are acidic, those of lower SiO_2 are more basic.

Table 2 lists the igneous rock types covered to date (1 June 1975), and the number of entries for each type. Obviously, there are several categories which require much more data, before statistical significance can be ascribed.

Preliminary analysis indicates that within both extrusive and intrusive igneous rock types, the alkaline rocks (termed alkali feldspathoidal on Table 1), have the overall highest radioactivity. Consequently, of the alkaline rocks, those that are richest in Na and K, termed peralkaline, are the most radioactive, containing U and Th in the range of tens to thousands of ppm, and up to several per cent K. The accepted criteria for peralkalinity is those rocks wherein $\frac{Na_2O + K_2O}{Al_2O_3} > 1$ (Sørensen, 1974). Peralkaline areas, exemplified by the Poços de Caldas igneous complex, are found at many locations throughout the world. Figure 5 (based on information from Sørensen (1974), and discussions with geologic colleagues), illustrates the worldwide distribution of alkaline rock areas within which peralkaline areas of significant size have been noted. It is likely that some peralkaline areas are not indicated on Figure 5; at this juncture the map should be used only as an illustration of their broad distribution.

The youngest peralkaline areas are associated with present-day rift zones, regions of the earth's crust undergoing tension such as the East African Rift, Iceland, and the Basin and Range Province of the western United States. Some very old peralkaline regions, such as the one in South

TABLE 2

GEODOSE STATUS: 1 JUNE 1975

Category	Number of data entries for U and Th	Number of data entries for K	Mean calculated dose rate ($\mu R\ h^{-1}$)	Standard deviation
ACID INTRUSIVE	374	340	15.28	9.64
ACID EXTRUSIVE	9	2	13.18	
INTERMEDIATE INTRUSIVE	170	167	9.04	5.34
INTERMEDIATE EXTRUSIVE	17	2	3.7	
BASIC INTRUSIVE	109	68	1.96	2.02
BASIC EXTRUSIVE	50	26	2.39	1.48
Total Entries	729	605		

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TABLE 3

GEODOSE STATUS - DETAIL: 1 JUNE 1975

Category	U/σ (ppm)	Th/σ (ppm)	K/σ (%)
ACID INTRUSIVE	4.33 σ 3.59	23.72 σ 21.65	3.22 σ 2.25
INTERMEDIATE INTRUSIVE	2.96 σ 2.40	11.41 σ 9.29	2.13 σ 0.85
BASIC INTRUSIVE	0.66 σ 0.71	2.23 σ 3.03	0.58 σ 0.62
BASIC EXTRUSIVE	0.83 σ 0.63	2.38 σ 1.94	0.70 σ 0.41

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Greenland (age 1 to 1.2 million years) were also associated with rift zones whose faults probably controlled their emplacement.

As well as with the acidic and peralkaline igneous rocks, high radioactivities are also associated with carbonatites; carbonate-rich intrusives which are generally in close proximity, and chemically related, to peralkaline areas.

It follows then that erosion, transportation, and deposition of minerals from acidic and peralkaline igneous regions can lead to formation of sedimentary radioactive deposits, such as the monazite sands of India, Ceylon, and Brazil. Similarly, weathering in-place of igneous rocks may result in accumulations of radioactive resistate minerals in lateritic soils. Thus, a worldwide map of potential areas of high natural radioactivity would have many more locations than just the peralkaline areas, shown on Figure 5. It is expected that the GEODOSE Project will help to define such areas.

Acknowledgment

The authors wish to acknowledge the continued support for the project by EG&G, Inc., and thank Clyde Jupiter and Zolan Burson of that organization for their encouragement.

References

Beck, H. and G. de Planque, 1968, The radiation field in air due to distributed gamma-ray sources in the ground, USAEC Health and Safety Lab. Rept. HASL-195.

Phair, G. and D. Gottfried, 1964, The Colorado Front Range USA as a uranium and thorium province, in J.A.S. Adams and W. Lowder eds., "The Natural Radiation Environment," Univ. of Chicago Press.

Sørensen, H., ed., 1974, "The Alkaline Rocks," John Wiley and Sons, New York.

Wollenberg, H. A. and A. R. Smith, 1972, Geologic factors controlling terrestrial gamma-ray dose rates, in J. A. S. Adams, W. Lowder, and T. Gesell eds., "The Natural Radiation Environment II," Proc. of Int. Symp., Conf.-720805-P2, USERDA.

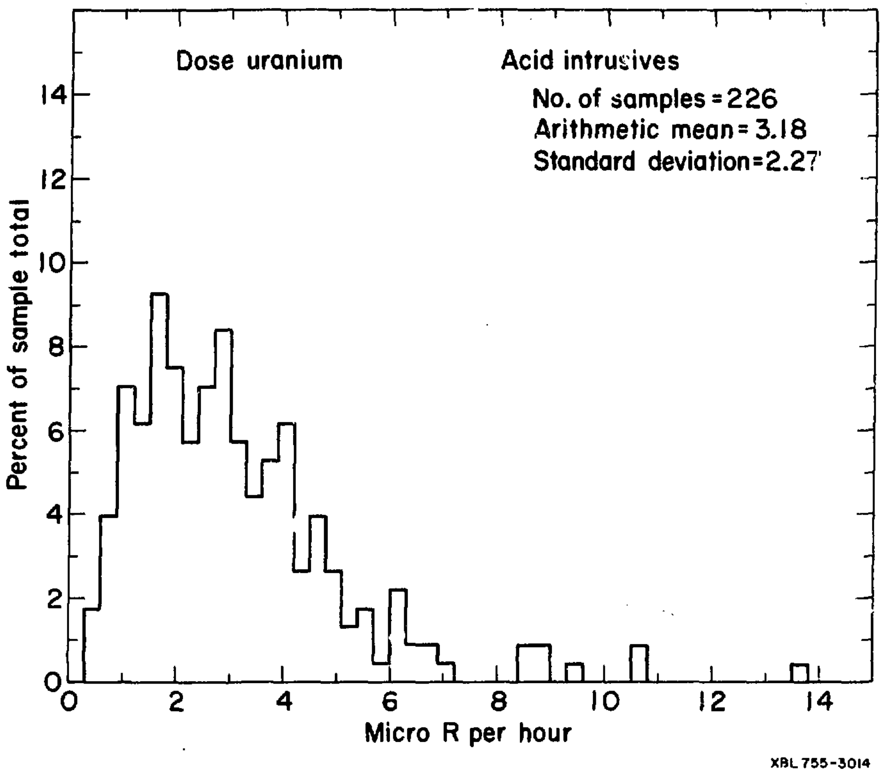

Fig. 1. Frequency distribution of gamma-ray exposure rates for U in uranium in acidic intrusive rocks.

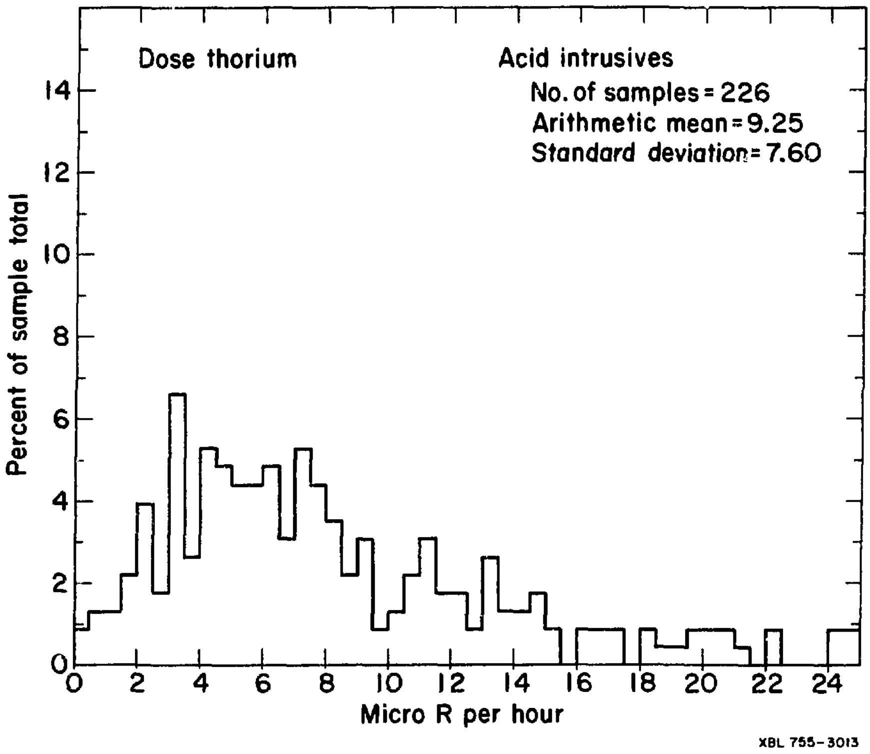

Fig. 2. Frequency distribution of gamma-ray exposure rates for thorium in acidic intrusive rocks.

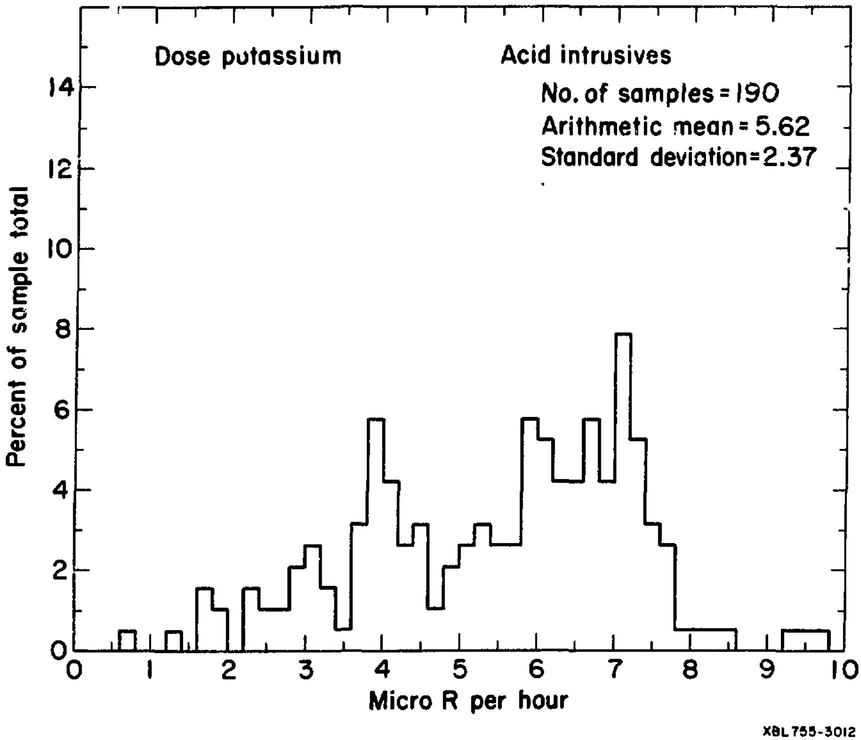

Fig. 3. Frequency distribution of gamma-ray exposure rates for potassium in acidic intrusive rocks.

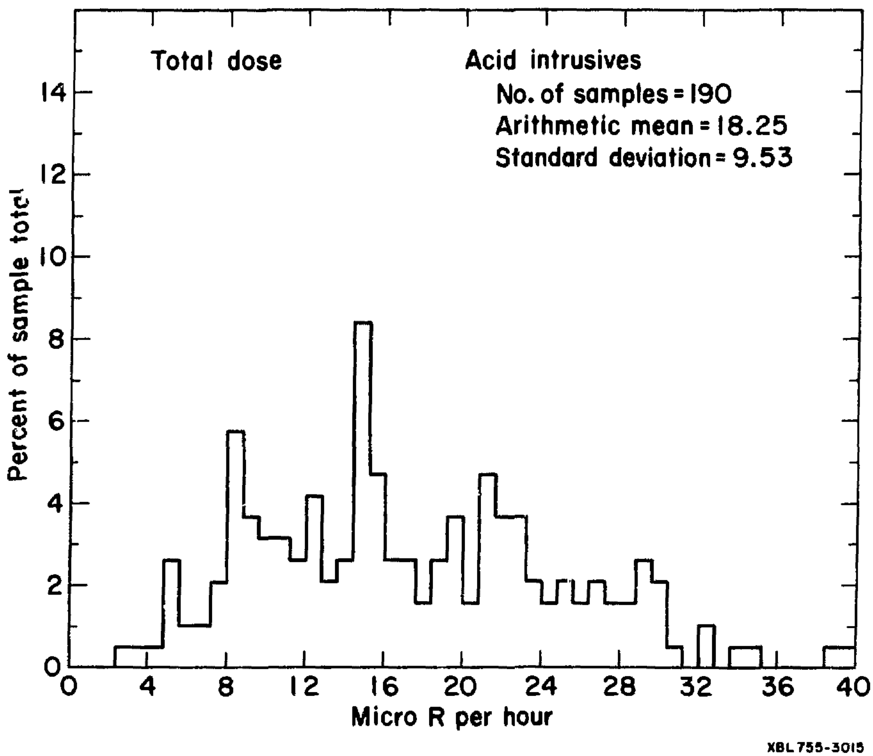

Fig. 4. Frequency distribution of total gamma-ray exposure rates for acidic intrusive rocks.

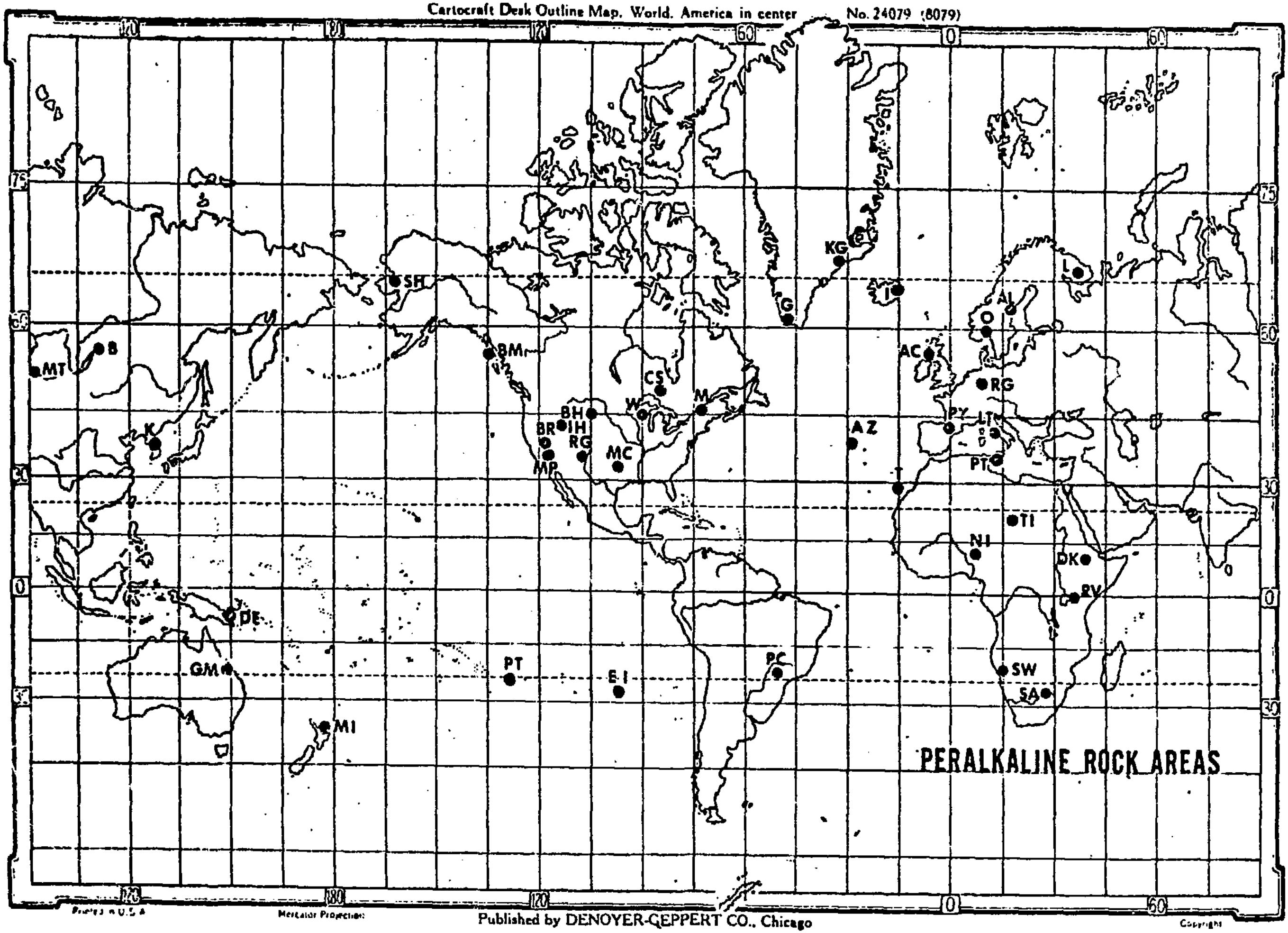

Fig. 5. World map showing locations of alkaline rock areas within which peralkaline intrusive bodies of significant size may occur. Legend: Refer to following page.

Europe

L	Lovozero
O	Oslo Graben
AC	Scotland - Ailsa Craig (Curling Stones)
RG	Rhine Graben (Laacher See)
LT	Latium
PT	Pantelleria
AL	Alnö Island

Islands

I	Iceland (Midhyma-Comendite)
AZ	Azores
T	Canary - Volc. Theide
EI	Easter Island
PT	Pitcairn Island
MI	Mayor Island (New Zealand)
DE	D'Entrecasteaux Islands (New Guinea)

North America

SH	Selawik Hills, Alaska
BM	Bokan Mountain, Alaska
CS	Canadian Shield - Ontario
M	Monteregian Hills - Quebec
BH	Black Hills
IH	Iron Hill, Colorado
BR	Basin and Range Province
RG	Rio Grande Rift
MC	Magnet Cove - Wichita Mountains
MP	Mountain Pass
W	Wausau

Greenland

G	Gardar Province
KG	Kangerdlugsuak

Africa

TI	Tibesti Mountains
NI	Nigeria - Jos Plateau
RV	Rift Valley
DK	Danakil Depression - continued into Aden
SA	South Africa - Pilanesberg, Vredefort
SW	Southwest Africa - Cape Cross → Brandenberg

South America

PC	Poços de Caldas - Araxá

Asia

B	Baikal
MT	Mongol - Tuva Province
K	Korea