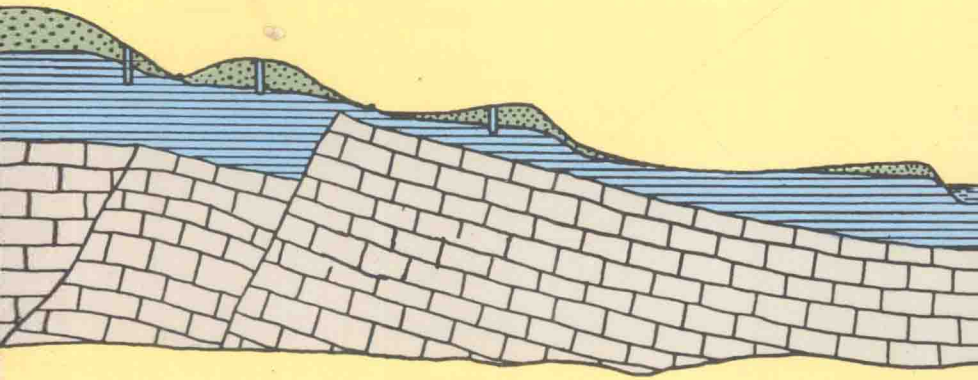
FACTORS OF SOIL FORMATION

A System of Quantitative Pedology



Hans Jenny

FACTORS OF SOIL FORMATION

A System of Quantitative Pedology

HANS JENNY

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FOREWORD TO THE DOVER EDITION

Giants were on the earth in those days
—*Genesis 6:4*

Hans Jenny was born 1899 in Basel, Switzerland, and died 92 years later near his adopted home of Berkeley, California. Between these two moments in time lies a life lived deliberately. It would be difficult to state when Jenny's career in science began, but it is true to say it ended only with his death. His *oeuvre* ranks among those of the giants in the earth sciences. Even within this rarefied atmosphere of intellectual achievements, his book *Factors of Soil Formation* stands out as a masterpiece.

Factors of Soil Formation, subtitled *A System of Quantitative Pedology*, is not a textbook, as is commonly stated, but is instead a scientific methodology. More fundamentally, it is a way of seeing the physical world. Within any science there are few books of this type, and within a science as young as pedology, there are arguably no others of such stature. Like Darwin's *Origin of Species* or Lyell's *Principles of Geology*, Jenny's *Factor's of Soil Formation* is, to use Darwin's description (1), "one long argument."

What is the "long argument" contained in *Factors of Soil Formation?* The book is a detailed discussion of the nature of the earth's terrestrial environment and a method of subdividing and studying it. First, soils are recognized as being part of a continuum of components at the earth's surface. Therefore, the distinction between soil and environment is an arbitrary, human construct. Second, given this statement, it is nonetheless possible to subdivide this continuum into systems, or units of study, whose boundaries can be quantitatively, although somewhat arbitrarily, defined—both in time and space. Third, the properties of the system in question "may be described accurately by indicating the initial state of the system, the reaction time, and conditioning variables" (2, p. 14), which Jenny combined and designated as "independent variables" or "soil-forming" factors. These factors are independent of the system being studied, and can be made to vary independently of one another through the judicious selection of study sites. Chapter I consists of a detailed and rigorous discussion of these points. It is impossible to summarize briefly the contents of this critical chapter, and an appreciation of its subtleties and complexities is the

reward of repeated readings. One of the greatest simplifications, and misrepresentations, of this chapter and the book in general has been to present Jenny's complex theory as simply:

$$s = f(cl, o, r, p, t, \ldots),$$

which is equation 4 in *Factors*. As Jenny lamented many times in later years, "the equation looks simple, but it's not." Indeed, the bulk of the book, Chapters III through VIII, is devoted to a deeper theoretical definition of each state factor, and empirical data selected to illustrate the principles of the theory. Chapter II, "Methods of Presentation of Soil Data," is a seemingly curious inclusion that summarizes various ways of numerically representing soil properties. While the argument of this chapter might seem self-evident to us today, it was critical to Jenny's vision that soil properties be measured quantitatively, and expressed numerically, thus allowing them to be mathematically correlated to the various state factors.

Jenny's book presents a factorial, or "formalistic" (2, p. 18), theory whose functional relationships are empirically derived from either experimental or observational measurements of soils. As a result, it does not tell us about mechanisms, or types, of pedogenic processes; "it is phenomenological" (3). In order to answer questions regarding mechanisms, one must resort to different theories. The state-factor theory *is*, however, quantitative. Numerous graphical relationships, many of them mathematically expressed, dominate the book. As such, *Factors of Soil Formation* provides an impressive compilation of present-day soil property/state-factor relationships and provides the quantitative data needed for a "uniformitarian" analysis of soils of the past (4) or for predicting the role of soils in ameliorating environmental effects of human activity.

We are commonly introduced to important scientists through textbooks. In photographs, invariably taken during the latter stages of the person's career, the scientist stares rigidly at us from the page. Their careers, and lives, summarized in a few paragraphs, portray a life of duty, perseverance and sacrifice. None of this, of course, gives us a sense of the human spirit that guided the intellect.

It was my good fortune that my life intersected with that of Hans Jenny when I was still a young man. While a graduate student, on a trip that brought me near Berkeley, I spontaneously made an appointment to meet him in his office on the Berkeley campus. That rainy day, in the winter of 1982, was the first of what were to be many visits I made to his small, cramped retirement quarters in 118 Giannini Hall. Sitting on the wicker lawn chair, reserved for his office guests, I was questioned, in the best Socratic tradition, about the conceptual aspects of my doctoral research. Topics of discussion were never selected trivially with Hans, for it was one of his most frequent comments about pedology (consis-

tently he seems to have applied it to his own life) that "we need to discuss theories more."

And so we did. And, probably, so did anyone who wandered into his office, regardless of their original intent. In his gentle way, Hans would guide himself, and his visitor, through a rigorous analysis of the logic of his or her beliefs. The Hans Jenny I knew was a man whose intellect was matched by humility, seasoned with a dry wit and sense of humor. Thoroughly happy, standing before a large audience honoring him at his eighty-fifth birthday, he said, "I disagree with much that has been said about me, for all that I think I can say about myself is that I tried to understand nature." Then, with a large smile on his face, he added, "I thank you for what you have said about me—true or untrue. I feel that it was much nicer to hear these sentiments expressed at an occasion such as this than in an obituary column. I'll remember this all one day, when I'm out there pushing up daisies."

I found it difficult to spur him into providing a personal background to his work. Tidbits, offered rarely, were captivating. Over a period of several years interviews by two individuals became part of his oral history (5), a text of over three hundred pages. Although clearly pleased with its publication in 1989, he remarked to me, "I don't think it's very good," primarily from, it now seems to me, a self-deprecating response to all the attention. Yet, in true Jenny style, he made a lively speech at the dedication ceremony for the history, humorously remarking that "as I get older and live long enough, most of my former enemies are gone and I'm getting all sorts of recognition and awards for my contributions."

It has been stated that a great scientific achievement is the rare result of the right combination of person, place and time (6). It is intriguing to consider how these factors combined in Jenny's case to provide the inspiration that created the concepts in *Factors of Soil Formation*. Hans Jenny arrived in the United States, in the fall of 1926, as a Rockefeller Fellow with an invitation to work in the laboratory of the future Nobel laureate Selman Waksman. While working in Waksman's lab, he participated in the group seminars. A recollection of one of these seminars (5) provides a glimpse that Jenny was already beginning to formulate a theoretical basis of soil formation. "... I gave a few interesting seminars. For example, in Zurich, we had a student who tried to correlate the European soil types with rainfall and evapotranspiration. Alfred Meyer was his name. He developed a sort of a scheme, a NS–quotient, that permitted correlating climatic moisture values with soils. So, while working under Waksman, I took that over and very boldly constructed a climatic moisture map of the United States saying, 'There is no law against doing it.' I predicted, for example, that [In] this place (e.g. Kansas) you must have a Chernozem. You must have a soil with a lime horizon.' Well, that impressed him. I didn't know if it was true. I said it must

be so because I believed whole-heartedly in this climatic dependency, which was an oversimplification. But nevertheless, I brought these together and talked about humus, especially where much humus should be found according to climatic principles. Waksman was quite impressed with this. He always invited me home and took an interest in my private life, too."

Thus, with limited field experience, restricted entirely to the soils of Europe, Jenny began formulating a theory that allowed him to predict the distribution of soil properties based on external variables. The development of theory in the earth sciences, *a priori* to field observation, is probably not as rare as one might expect (7). What remained for Jenny was the opportunity to see the vastness of nature in person, and recognize the applicability of his evolving ideas.

This opportunity came soon. In the summer of 1927, Jenny was appointed as an official Swiss delegate to the First International Congress of Soil Science in Washington, D.C. The grand finale of this important event was a continental excursion, by train, to view the soils and landscapes of North America. For Jenny, and the effect it had on his ideas, this excursion must be compared in importance to Darwin's voyage on the *Beagle*. He later recounted:

"To me, the tour experience was a thrill and it opened a new world. I was impressed when we went from Washington south and saw the southern red soils and, a few weeks later, the black soils of Canada. I searched for a connection between the two. There must be a relationship, I thought, but in Europe the landscape is all cut up. The Alps wreck climatic gradients and smoothness of land, whereas in the wide plains of the United States there they were.

"The red soils of the South and the black soils of Canada were showcases of the climatic theory of soil formation. No doubt, our European textbooks by Ramann and Glinka were right in principle. I was intrigued by the 1,000 mile-long smooth transition of the Great Plains area, without interruption by massive mountains a la (the) Alps. The rolling plains, I fancied, must harbor the secret of mathematical soil functions. At times I could hardly sleep thinking about it."

The effect on his research was immediate. Following the excursion, Jenny was offered a chance to spend a year (which ultimately turned into a permanent position) at the University of Missouri at Columbia. Of this period, Jenny said, "Later, after the tour, I think that the lack of information on the connections (between soils across the continent) pushed me to try to find solutions, especially when I started teaching" (5). Beginning in 1928 (8), a series of research papers was published that searched for quantitative links between climate and various soil properties. However, the journey between these early papers and the detailed definitions and concepts presented in *Factors* was a long one. It included an exploration for other variables, years of detailed conceptual discussions with numbers of his colleagues, and a move to the University of California

at Berkeley, where he realized his dream of filling the position first held by one of his intellectual inspirations, E. W. Hilgard.

The question might now be asked, "Why should one read a book that is now more than a half-century old?" In reply, I would respond with these arguments. First, *Factors of Soil Formation* is a theory of how soils and, although Jenny did not use the word, ecosystems form. Just because a theory is old, that does not mean it is out of date. While many advances have been made on *process* models of soil development, there have been no new factorial theories to replace that outlined in *Factors*. This should be of no great surprise, since the replacement of one scientific theory by another occurs so rarely, and has such a great significance, that it is said to constitute a scientific revolution (9). Secondly, for many of us, our introduction to Jenny's ideas has been presented to us through textbooks, many of which have oversimplified the vision contained in *Factors* or, in some cases, completely misrepresented it. Because the book has been out of print for much of the time since its first printing, the opportunity to read Jenny in its original form will prove to be an illuminating experience for many. Thirdly, the book is a pleasure to read. Its conciseness and clarity are matched by few books in the sciences. The numerous illustrations, which lend a pleasing visual quality to the book, were drawn primarily by Jenny himself. The book is packed with ideas that will stimulate any student of the earth today.

As for myself, I am greatly indebted to Dover Publications for this reprinting of *Factors of Soil Formation*. My copy, an original 1941 edition that was a gift from a retired colleague, was autographed by Jenny a few years before his death. During numerous rereadings of this book, I often wished to make notes, and highlight certain sections, but refrained because I did not want to mar what is, to me, a priceless work. However, with my new Dover edition, I promise, in future rereadings, to fill the margins with the ideas and thoughts that the text inspires. For I remain a student of Jenny.

RONALD AMUNDSON

BERKELEY, CALIFORNIA
December 1992

Literature Cited

1. DARWIN, C.: "The Origin of Species by Means of Natural Selection," John Murray, 1859.
2. JENNY, H.: "Factors of Soil Formation. A System of Quantitative Pedology," McGraw-Hill Book Company, Inc., New York, 1941.

3. AMUNDSON, R., and JENNY, H.: The place of humans in the state factor theory of ecosystems and their soils, *Soil Science*, 151: 99–109, 1991.
4. RETALLACK, G. J.: "Soils of the Past: An Introduction to Paleopedology," Unwin-Hyman, London, 1990.
5. JENNY, H.: "Hans Jenny. Soil Scientist, Teacher, and Scholar. Interviews by D. Maher and K. Stuart," *University History Series*, Regional Oral History Office, The Bancroft Library, University of California, Berkeley, 1989.
6. GOULD, S. J.: Darwin's Middle Road. In "The Panda's Thumb. More Reflections in Natural History," W. W. Norton and Company, New York, 1980, pp. 59–68.
7. GOULD, S. J.: "Time's Arrow, Time's Cycle. Myth and Metaphor in the Discovery of Geologic Time," Harvard University Press, Cambridge, Massachusetts, 1987.
8. JENNY, H.: Relation of climatic factors to the amount of nitrogen in soils. *J Am. Soc. Agron.*, 20: 900–912, 1928.
9. KUHN, T. S.: "The Structure of Scientific Revolutions. Second Edition," The University of Chicago Press, Chicago, 1970.

PREFACE

The College of Agriculture of the University of California offers a four-year curriculum in soil science. The first two years are devoted to the fundamental sciences, whereas the remaining period covers the field of soil science and related agricultural and scientific phases. Among the subjects prescribed, the four-unit course on "Development and Morphology of Soils" includes a study of soil-forming factors and processes of soil genesis. The present monograph is an extension of the first part of the course. The book must be classified as an advanced treatise on theoretical soil science.

Pedology is sometimes identified with the section of the domain of soil science that studies the soil body in its natural position. It is in this sense that the term is used throughout the book. As far as the author is aware the approach and presentation of the subject matter are entirely novel. They are the result of intensive research and a dozen years of teaching, beginning with an instructorship at the Federal Technical Institute in Zurich, Switzerland, followed by an association with the University of Missouri from 1927 to 1936.

It is impossible to acknowledge adequately and specifically the assistance, criticisms, and encouragement rendered by scores of colleagues and students. To all of these the author tenders his sincere thanks. The author wishes to express his deep indebtedness to Dr. Roy Overstreet, who has given much time to long and profitable discussions. He has improved the manuscript logically and technically. In particular his contribution to the elucidation of the role of organisms in the scheme of soil formers will be appreciated by all who have been baffled by the complexity of the biotic factor. The author's profound thanks are also due to Dr. J. Kesseli of the Department of Geography, who read the manuscript and offered many helpful suggestions. The author extends his appreciation to Dr. R. H. Bray of the University of Illinois and to Dr. A. D. Ayers of the United States Salinity Laboratory for the use of unpublished data on loessial soils and

on salinization. It is a pleasure to acknowledge the cooperation of members of the personnel of the Works Progress Administration Official Project No. 465-03-3-587-B-10, who assisted in the stenographic work and furnished translations from recent Russian literature.

The author wishes to add that the data selected from the literature are presented to illustrate pedological relationships. The selection does not reflect the author's opinion regarding the validity of these data nor does it indicate any discrimination against investigations that are not mentioned in the text.

HANS JENNY.

BERKELEY, CALIF.,
June, 1941.

INTRODUCTION

The vast importance of the soil in the development of various systems of agriculture and types of civilizations has long been recognized; but it is only within the last few decades that soils as such have been studied in a scientific manner. During thousands of years mankind has looked upon soils mainly from the utilitarian point of view. Today it is being realized more and more that the soil per se is worthy of scientific study, just as animals, plants, rocks, stars, etc., are subjects for theoretical research and thought. There is every reason to believe that any advance in the fundamental knowledge of soils will immediately fertilize and stimulate practical phases of soil investigations.

Since the beginning of the present century a great amount of work on soil identification and mapping has been carried out in all parts of the world. The detailed descriptions of the soil types investigated embrace hundreds of volumes, charts, and atlases. Attempts to coordinate the great mass of data frequently have been made, but almost exclusively along the lines of soil classification. The idea of classification has stood foremost in the minds of many great soil scientists of the past, and the present-day leaders in field soil studies continue in this same direction.

It should be remembered, however, that classification is not the only way to systematize facts. Data can also be organized by means of laws and theories. This method is characteristic of physics, chemistry, and certain branches of biology, the amazing achievements of which can be directly attributed to a great store of well-established numerical laws and quantitative theories. The present treatise on soils attempts to assemble soil data into a comprehensive scheme based on numerical relationships. Soil properties are correlated with independent variables commonly called "soil-forming factors." It is believed that such a mode of approach will assist in the understanding of soil differentiations and will help to explain the geographical distribution of soil types. The ultimate goal of functional analysis is the formula-

tion of quantitative laws that permit mathematical treatment. As yet, no correlation between soil properties and conditioning factors has been found under field conditions which satisfies the requirements of generality and rigidity of natural laws. For this reason the less presumptuous name, "functional relationship," is chosen.

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CHAPTER VIII

FACTORS OF SOIL FORMATION

CHAPTER I

DEFINITIONS AND CONCEPTS

As a science grows, its underlying concepts change, although the words remain the same. The following sections will be devoted to an analysis of terms and concepts such as soil, environment, soil-forming factors, etc. The present method of treatment of soils is only one out of many, but it behooves a scientific system to be consistent in itself.

Preliminary Definitions of Soil.—In the layman's mind, the soil is a very concrete thing, namely, the "dirt" on the surface of the earth. To the soil scientist, or pedologist, the word "soil" conveys a somewhat different meaning, but no generally accepted definition exists.

Hilgard (4) defined soil as "the more or less loose and friable material in which, by means of their roots, plants may or do find a foothold and nourishment, as well as other conditions of growth." This is one of the many definitions that consider soil primarily as a means of plant production.

Ramann (7, 8) writes: "The soil is the upper weathering layer of the solid earth crust." This definition is scientific in the sense that no reference is made to crop production or to any other utilitarian motive.

Joffe (5), a representative of the Russian school of soil science, objects to Ramann's formulation on the grounds that it does not distinguish between soil and loose rock material. According to Joffe,

> The soil is a natural body, differentiated into horizons of mineral and organic constituents, usually unconsolidated, of variable depth, which differs from the parent material below in morphology, physical proper-

ties and constitution, chemical properties and composition, and biological characteristics.

It is problematic whether any definition of soil could be formulated to which everyone would agree. Fortunately there is no urgent need for universal agreement. For the purpose of presentation and discussion of the subject matter it is necessary only that the reader know what the author has in mind when he

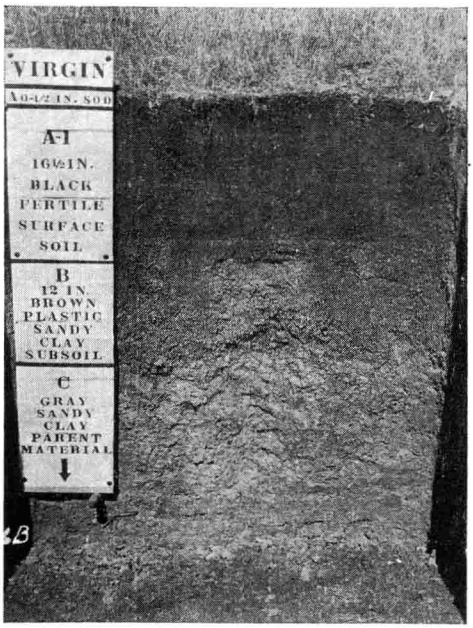

FIG. 1.—Virgin prairie soil, Missouri. This soil profile shows a diffusion-like distribution of organic matter with depth. (*Courtesy of Soil Conservation Service.*)

uses the word "soil." This common ground will be prepared in the following sections.

The Soil Profile.—In order to gain a more concrete notion of the term "soil," the reader is directed to turn his attention to Figs. 1 and 2, which represent typical soils as found in the United States and other parts of the world. The pedologist's concept of soil is not that of a mere mass of inorganic and organic material; rather it takes cognizance of a certain element of organization that persistently presents itself in every soil. Although soils