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Soil maps of the world

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ABSTRACT

Soil maps depict the distribution of soils on the earth's surface and have an important role in aggregating our knowledge of soil resources. The maps are based on geographic rules of spatial arrangement of soils and at each scale show soil distribution patterns. Here we review how world soil maps have evolved from the early 1900s to the present. The first world soil map was published in 1906 by K.D. Glinka and included 18 soil classes that more or less corresponded to the climatic zones of the Earth. This first map was followed by a number of world soil maps at various scales developed in different countries. With increasing information following extensiv\e soil surveys in all parts of the world, world soil maps have become more precise, less schematic and eventually have led to the FAO–UNESCO soil maps. Over time, world soil maps show an increasing complexity of the depicted soil pattern but most of the maps were concept-dependent rather than data-derived and are influenced by the underlying systems of soil classification. In recent years, a project in soil mapping was developed that is based on the mapping of key soil properties rather than soil classes (GlobalSoilMap project). In the future, world soil maps should include both soil classes and soil properties and be accompanied by a set of interpretative tools.

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1. Introduction

We live in a world of maps. The entire Earth's surface has been projected in millions of two-dimensional images at a wide range of scales. The first maps of a territory appeared in pre-historic time as paintings or stone block constructions (Utrilla et al., 2009). Harvey (1987) stated that these maps were one of the oldest forms of human communication. Complex maps that tried to maintain the proportions of the distances were made in Mesopotamia as early as 2500 years BC (Millard, 1987). Egypt was another center of early map production (Harrell and Brown, 1992). Mapping also developed in China, where the first maps were made by 300 years BC (Hsu, 1993; Needham, 1986). The main achievements in Greek cartography took place from about the sixth century B.C. to the culminating work of Ptolemy in the second century AD. The Greeks were the first to attempt making world maps (Harvey, 1987).

The first makers and users of the maps were sailors, soldiers, and merchants. Cartography changed from routing to increased detail between locations. Geographers collected the information and added it to the maps. Much time was needed to collect sufficient data for covering significant areas with thematic maps like climate maps. Special systems of symbols were developed to show the distribution of natural phenomena on thematic maps. For example, the climatic maps could be produced only after Alexander von Humboldt introduced the idea of isotherms in the early 1800 s (von Humboldt and Bonpland, 1805).

A map on Turin papyrus from Egypt and dated to 1150 BC is considered to be the first geologic map, and it shows the mining areas and the sediments along the way to these mines (Harrell and Brown, 1992). The first scientific geological map was published in 1815 after William Smith, who has been recently recognized to be one of the founding fathers of geology, had proposed stratigraphy as a basis for classifying and mapping geological units (Winchester, 2002). Smith called his map "a delineation of soil strata", although he was dealing with deep sedimentary layers. The first biogeographical map was published in the third edition of the *Flore Française* by Lamarck and Candolle in 1805 (Ebach and Goujet, 2006). This map showed the distribution of floristic regions in France, and it was based on biogeographical concepts, such as the historical and ecological bases for the distribution of vegetation.

In summary, the development of thematic cartography depended on the scientific progress of particular disciplines. The first scientific thematic maps appeared at the beginning of the 19th century, when it was realized that the spatial distribution of natural phenomena was governed by rules, which allowed these phenomena to be depicted on maps.

Global knowledge about the distribution of the main characteristics of the Earth's geography emerged in the 19th century. The first world map of climate appeared in 1823: it was an isotherm map published by Woodbridge, based on early drafts by Alexander von Humboldt (Woodbridge, 1823). The general gradients of temperatures

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were already known but climate distribution on the planet was only partially understood, and the delineation of isotherms proved to be a useful way to show the spatial distribution of climates.

The global distribution of vegetation was first mapped by Grisebach (1872), who related it to the distribution of climates. The first quantitative classification of world climates was prepared by the German scientist Wladimir Köppen (1846–1940) in 1900. The world map based on this classification was prepared by Rudolf Geiger in the middle of the 20th century (Kottek et al., 2006).

The geological features and structure of the globe were more difficult to map. The first geological map of the world was made by Ami Boué in 1843 (Schweizer and Seidl, 2011); the map was based on reports on the geological structure of various parts of the world and on perceived relationships between geoforms and topography, on the one hand, and the geological composition, on the other hand. For example, it showed flood basalt in the center of the African continent, like in India, because Africa resembled India in shape.

Soil maps constitute an integral part of the mapping coverage of the Earth. These maps, although too general for use on the farm or even regional level, have an important role in aggregating our knowledge of the soil resources of our planet. In this paper, we explore how world soil maps have been transformed throughout the centuries and provide some discussion on the future of world soil maps. The objectives of this paper are to (i) explore and describe what world soil maps have been published, (ii) analyze the origin and methods in which they were constructed, (iii) analyze how they have been used, and (iv) discuss the future of world soil maps and their use.

2. Early regional or country soil maps

2.1. Some ancient soil maps

The first soil maps were produced in China, and Yugong (about 4000 years BP) prepared a map that depicted the distribution of soils in nine provinces (Gong et al., 2003). There was a need for maps for better land use planning to provide more taxes for the feudalist dynasties. Soils were mapped based on characteristics like soil fertility, soil color, soil texture, and soil moisture.

The Aztecs showed in a single document land ownership relations and soil productivity and properties. Codices of Santa Maria Assunta and the Vergara mapped plots owned by each family of a community, and each plot had in its central part a glyph indicating the type of soil. For describing the soils, 132 glyphs were used, including such elements as stone, points, backpack, thorn hill, eyes, teeth, manure, maize, water, and so on (Williams, 1976; Williams et al., 2008). The Aztecs developed a soil classification based on soil properties (fertility, texture, moisture, and genesis), topographic location, vegetation, and farmers' practices. This soil classification, with up to 45 classes, was used for several purposes, including taxation, soil management, medicinal usage, and construction (Williams, 1976).

2.2. Early scientific soil maps

Soil cartography, which originated in Germany, France, Austria, the Netherlands, and Belgium in the 1850 s and 1860 s, was based on ideas and classification approaches from agrogeology. In 1806 S. Staszic compiled a multi-sheet geology/geomorphology/soil map of Eastern Europe (Grigelis et al., 2011). The start of the scientific study of soils is commonly dated to the middle of the 19th century, with the works of Senft (1857), Fallou (1862) and Orth (1877). These authors prepared soil or agrogeological maps (Table 1) based on the texture and humus content of the soil (Asio, 2005). In 1875, A. Orth promoted the soil profile as an essential basis for agrogeological mapping in Germany (Brevik and Hartemink, 2010). Expanding on this, the German scientist M. Fesca published agrogeology and soil maps of Japan between 1885 and 1887 (Brevik and Hartemink, 2010). Earlier similar attempts were made in Ireland by Sir Robert Kane, with an emphasis on soil assessment (Horner, 1994) and in England (Morton, 1843), where soils were mapped based on the underlying geologic strata (Hartemink, 2009). In 1856 A.I. Grossul-Tolstoi compiled a soil map that was later acknowledged to have influenced V.V. Dokuchaev (Krupenikov, 1992). In the Netherlands the first soil maps were produced in the 1860s (scale 1:0.2 million) and the maps were largely lithological distinguishing between alluvial (Holocene) soils, diluvial (Pleistocene) soils and tertiary soils (Hartemink and Sonneveld, 2013).

The demand for soil mapping was greater in Russia and the USA than in Europe because of the need for the development of new and extensive territories for agriculture (Kellogg, 1974). In Russia, the Military Department published many maps showing items of interest to military operations, including relevant soil information, starting in 1812, and the Ministry of Government Properties started mapping soils for taxation purposes in 1838 (Krupenikov, 1992). The first soil map for the European part of the country was made by K. S. Veselovskiy in 1851 (scale 1:8.4 million) and then by V. I. Chaslavskiy in 1879 at a scale of 1:2.52 million (Krupenikov, 1992). Both Veselovskiy and Chaslavskiy were economists, and the soil maps were developed from interviews of landowners.

The earliest soil maps in the United States were part of state geological surveys; the first appears to have been a soil map of Massachusetts published in 1841; these early maps were geologic maps with the assumption that soils formed depended upon the underlying geology (Brevik and Hartemink, 2010). The 1882 soil map of Wisconsin by T.C. Chamberlin (1882) was unique in that it recognized that a geological map and a soil map were not necessarily one and the same (Hartemink et al., 2012). Soil mapping was almost completely based on soil texture and the geological nature of soil material. A somewhat similar approach was adopted later for the entire system of soil survey in the United States: the soil series were based mainly on the texture and some evident morphological features (Brevik and Hartemink, in press; Helms et al., 2002; Simonson, 1989).

2.3. Maps by Dokuchaev

World soil maps followed the first climatic and geological maps. As there was little global soil information, a global geographic theory was needed similar to that developed for the geological map. An important step in the development of this theory was when V.V. Dokuchaev related the distribution of soils to the factors of their formation. Although he was a geologist by training, Dokuchaev linked soils to the climate and corresponding vegetation. His ideas were possibly inspired by the biogeographical zoning of Alexander von Humboldt and earlier studies of soil-horizon division proposed by Fallou and Orth (Asio, 2005). The bioclimatic aspects of soil formation were emphasized for two reasons. First, the distribution of soils on the Russian Plain, with its relatively uniform periglacial deposits, was mainly related to climate and to a lesser extent to the parent material. Secondly, Dokuchaev found that the climate was a much better predictor for the soil distribution than the complex geology.

Dokuchaev considered making a global soil map. His archives contain an undated sketch drawing of a soil map of the world (Fig. 1). He drew the soil zones: glacial soils, podzolic soils, grey transitional soils, and chernozems. Further to the south the soil names were mixed with the climatic names: kastanozems (with a question mark) in Mexico, subtropical soils across the Eurasian continent, krasnozems (red soils) and zheltozems (yellow soils) in China. The southern hemisphere of the Earth was less well marked; it had mostly the names of the climatic vegetative zones such as “tropical areas”, “transition”, “pampas”, and “coniferous forest”. Dokuchaev was not sure if the distribution of soils was symmetrical on the Earth, and the amount of data from the Southern Hemisphere was insufficient for good extrapolation. For that reason he probably decided to make a map for the Northern Hemisphere alone that was published in 1899