

Soil Science Contribution to an Airplane Crash Investigation, Ruidoso, New Mexico

REFERENCE: Daugherty LA. Soil science contribution to an airplane crash investigation, Ruidoso, New Mexico. *J Forensic Sci* 1997;42(3):401-405.

ABSTRACT: Investigation of a plane crash near Ruidoso, New Mexico revealed foreign biological material and soil in the fuel system of the engine. In-flight accumulation of the soil was claimed by the plaintiffs as one cause for the crash. EDX X-ray maps and spectra were taken by the plaintiff's experts and showed patterns consistent with silicates. The defense hypothesis was that the soil accumulated after the crash while the debris was in a storage yard and exposed to the elements for several months. Many of the parts were covered in muddy water (mud puddles) before the plaintiffs investigated the parts for soil accumulation. The soil composition on the parts was found to be similar to that in the storage yard. Further, the plane was exposed to an intense fire after the crash, and if the soil had been subjected to such temperatures it would have oxidized to a red color. Soil from the storage yard, the crash site, and from an area in Montana where the plane landed on an unpaved runway was exposed to heat up to 1,000°C in the laboratory and the soil turned red. Soil from the fuel component was not red, although a small piece adhering to the outside of the wreckage was red suggesting exposure to the post-crash fire. It was concluded that the engine parts were contaminated with soil after the crash, and that pre-crash accumulation of soil, as a supplement or alternative to biological contamination, was not a viable explanation.

KEYWORDS: forensic science, December, 1989 Ruidoso, NM plane crash, criminalistics, soil science, soil comparison, airplane crash

In November, 1989, an aircraft flew from San Diego, California toward Ruidoso, New Mexico. The aircraft crashed a few moments before a scheduled landing near Ruidoso in Lincoln County, New Mexico, and a law suit was filed claiming contamination of the fuel system. I was contacted in November 1991 by representatives of the aircraft, engine, and engine part manufacturers to examine the wreckage for contamination from soil.

My specialty is soil genesis, soil morphology, and soil classification, and I conducted the study from this perspective. Soil genesis is the study of the formation of soils, soil morphology is the development of methodology for the description of soils, and soil classification is the development of a classification system to convey knowledge about soils and to compare soils from different regions. I had previously studied the soil types that exist in and around Ruidoso and Lincoln County, and also a sequence of soils that included a sample from under the current runway at the Ruidoso Airport (1). I had also participated in an intensive soil survey of the Fort Stanton area which surrounds the Ruidoso Airport (2).

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Received 29 May 1996; accepted 23 Sept. 1996.

Throughout this paper I am going to discuss soil from the engine part of the crashed aircraft, the soil at the crash site, at the aircraft storage yard, and from a remote airport in Montana.

During the course of the investigation, the plaintiff's experts made Energy Dispersive X-ray (EDX) maps and spectra of certain lever assemblies from the fuel control units (FCUs) that were in the accident aircraft. They also produced EDX spectra from soil samples from Sand Springs, Montana. The aircraft had previously flown to Sand Springs and landed on a dirt runway. The plaintiffs theorized that soil particles were ingested into the engine at Sand Springs. A plaintiff expert witness testified that he was of the opinion that the EDX spectra indicated that what was on the several levers of the FCU is consistent with silicates, quartz, and mafic minerals. The implication was that this composition identified the soil as coming from Sand Springs.

However, both of the latter groups are silicates, and most rock-forming minerals are silicates. I had an opportunity on several occasions to examine the FCU assemblies, and I observed soil on both assemblies and on the pads themselves. I agree that silicates were present, but nearly every soil in the world is made of silicate minerals. My view was that the information gained from EDX spectra was much too general to identify and understand the source of the soil. These lever assemblies were exposed to the elements after they were returned to the Sierra Blanca Regional Airport. They were stored outdoors there for several months in partially open cardboard boxes and exposed to rain and surface water. Visual inspection showed that the parts were covered with calcium carbonates from the calcareous soils, and with other salts, which is consistent with their having been exposed to water or mud. The soils there are also rich in calcium carbonate (1,2). A series of tests were performed to better characterize the soils and these are described below.

Materials and Methods

Soils were sampled in order to compare their composition, and to see if they were consistent or inconsistent with each other, using the plaintiff's techniques. Soils were collected in 1992 from the crash site, from the storage yard, and from Sand Springs. At Sand Springs samples were taken from both ends of the runway at a location where an aircraft would land, from the hanger area where airplanes are parked, and from a site adjacent to the runway on the south side near the hanger. The soils from all three sites were mollisols (ustolls and borolls) (1,3-6).

The eight soil samples (two from the crash site, two from the storage yard, and four from the Sand Springs Airport) were analyzed using EDX analysis. This was the same technique used by the plaintiff's experts on their samples. Each of the EDX analysis



FIG. 1—Location of crash and soil sample sites.

charts were done by counting for 100 s to be consistent with those done by the plaintiffs. These analyses were done in the SEAL Laboratory at El Segundo, California in May, 1992. EDX analysis allowed the whole spectrum from the soil samples to be recorded. Characteristic X-rays were emitted from the soil samples and separated according to their energy, which permitted simultaneous identification of a number of elements in the spectrum (7,8).

Soil samples from each of the three areas were also heated in a muffle furnace to simulate the effect of fire on the soil. One sample from the crash site, one from the storage yard, and two from Sand Springs were used in the experiment. The samples were heated at 100°C intervals ranging from 100°C to 1,000°C. The color of the soil at each heating increment was noted using the Munsell Color System (9,10).

Results and Discussion

Each of the eight charts produced by the EDX analysis look very similar in the relative proportion of the elements present (Fig(s). 2–9). Elements identified in the soil samples were carbon, oxygen, magnesium, aluminum, silica, potassium, calcium, and iron. Elements identified and their relative proportions on the charts are similar to those produced by the plaintiffs. Silica was the highest peak in all cases and each diagram was standardized on silica because it was the highest peak. All eight of the EDX analysis charts (four from Montana and four from New Mexico) were superimposed and compiled in one diagram (Fig. 10) in order to compare the sampling sites. The charts were superimposed by

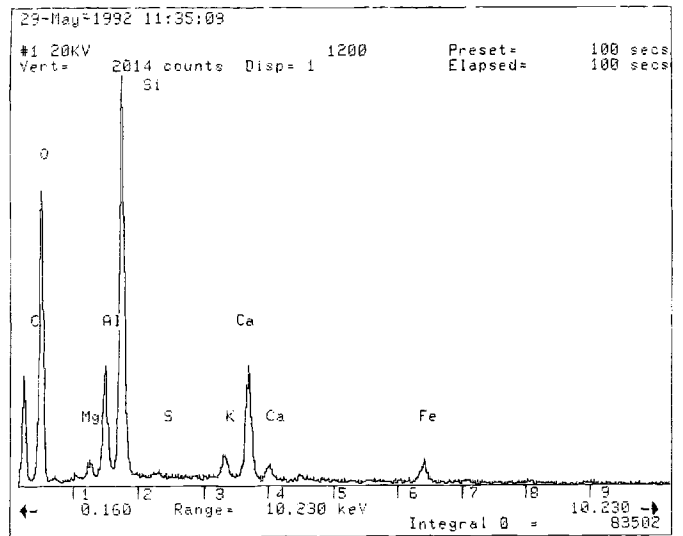


FIG. 2—Energy dispersive X-ray analysis of site 1, crash site.

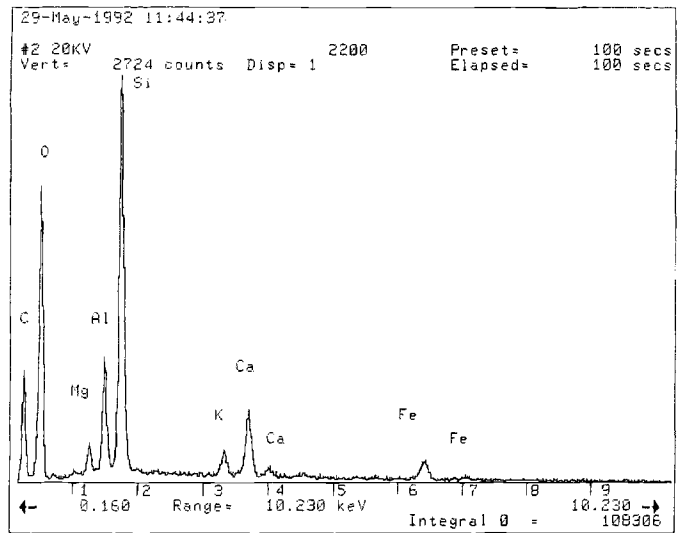


FIG. 3—Energy dispersive X-ray analysis of site 2, crash site.

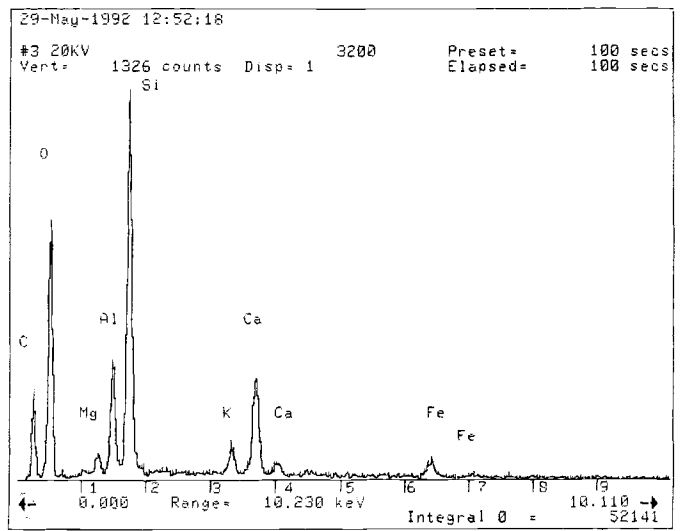


FIG. 4—Energy dispersive X-ray analysis of site 3, airport storage yard.

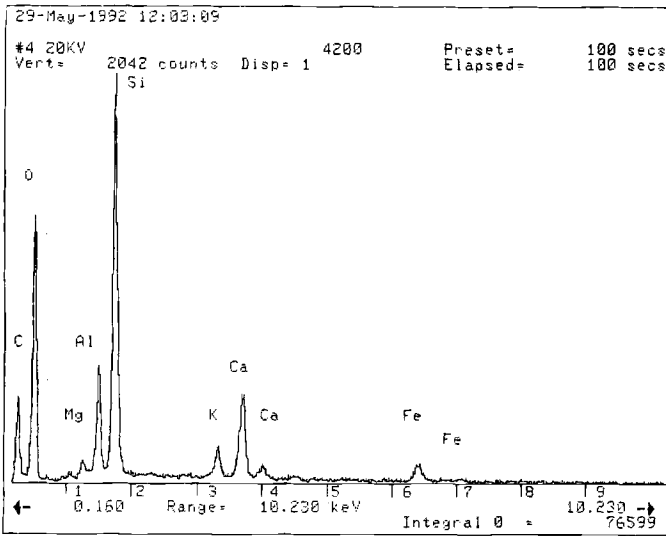


FIG. 5—Energy dispersive X-ray analysis of site 4, airport storage yard.

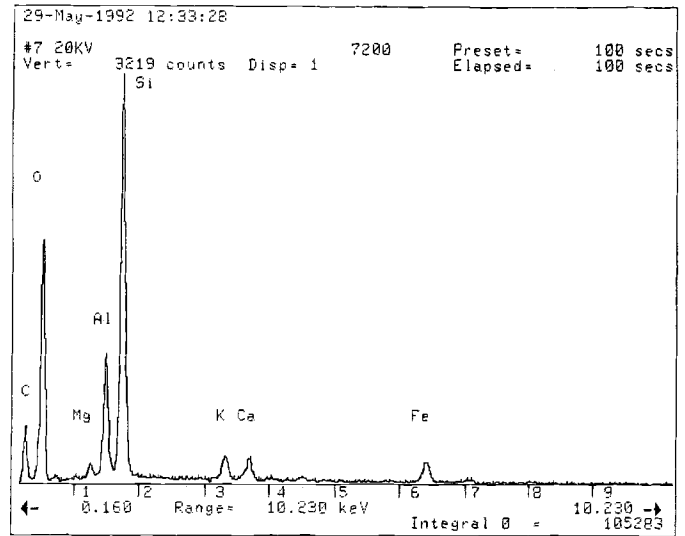


FIG. 8—Energy dispersive X-ray analysis of site 7, Sand Springs, MT.

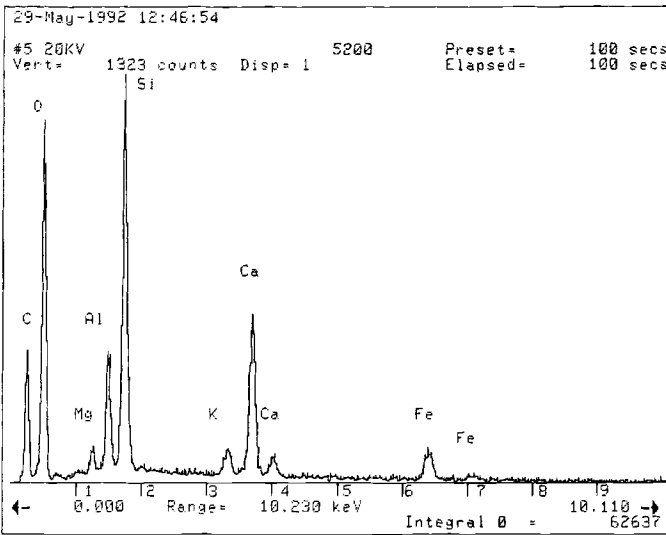


FIG. 6—Energy dispersive X-ray analysis of site 5, Sand Springs, MT.

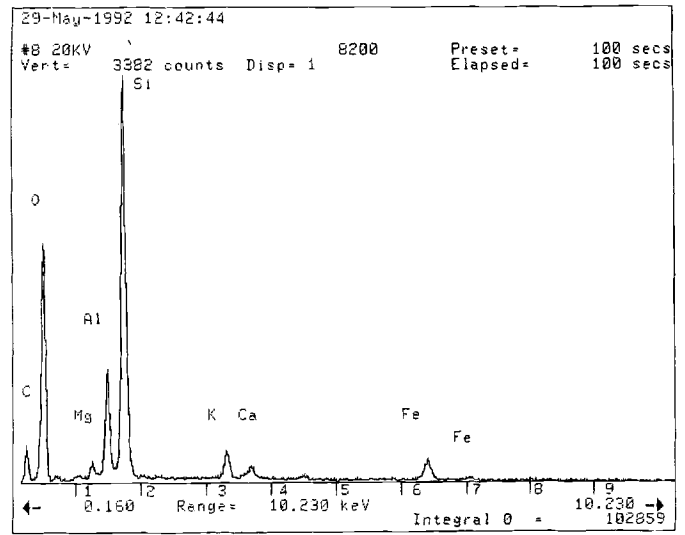


FIG. 9—Energy dispersive X-ray analysis of site 8, Sand Springs, MT.

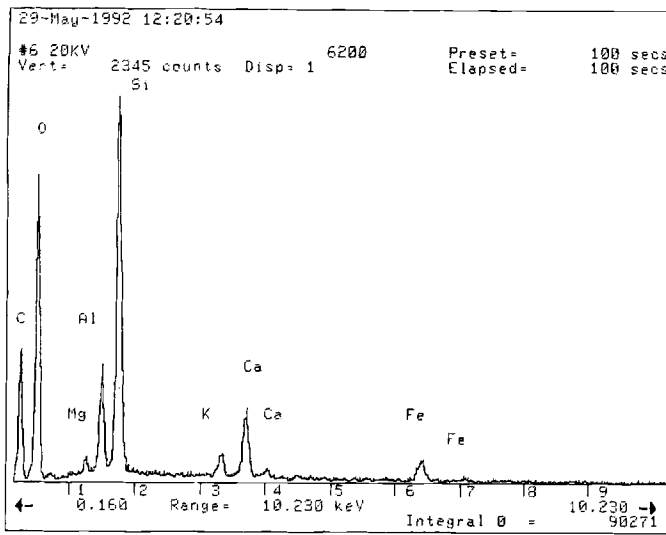


FIG. 7—Energy dispersive X-ray analysis of site 6, Sand Springs, MT.

measuring the peak locations. The vertical axis is the relative intensity of the X-ray.

The most important portions of the spectra used in comparison to the plaintiffs' spectra were the silica and aluminum peaks. The most important element to compare to silica is aluminum. Most soil minerals other than quartz are made up of a group of minerals which combine aluminum and silica, and as the soil or rocks weather, the amount of silica decreases and the relative amount of aluminum increases. The comparisons of aluminum to silica for these eight samples from three sampling locations is identical. Iron is the fourth most abundant element in the earth's crust (11). The amount of iron in the sample appears identical, and there is no diagnostic pattern among the samples or among the localities. Potassium and magnesium also appear identical on the charts.

Other elements such as carbon, oxygen, and calcium are more variable in these diagrams. Carbon and oxygen are associated with the organic matter in the samples and this can vary greatly. Carbon and oxygen are also associated with calcium to form calcium carbonate. Calcium carbonate is a secondary mineral and forms

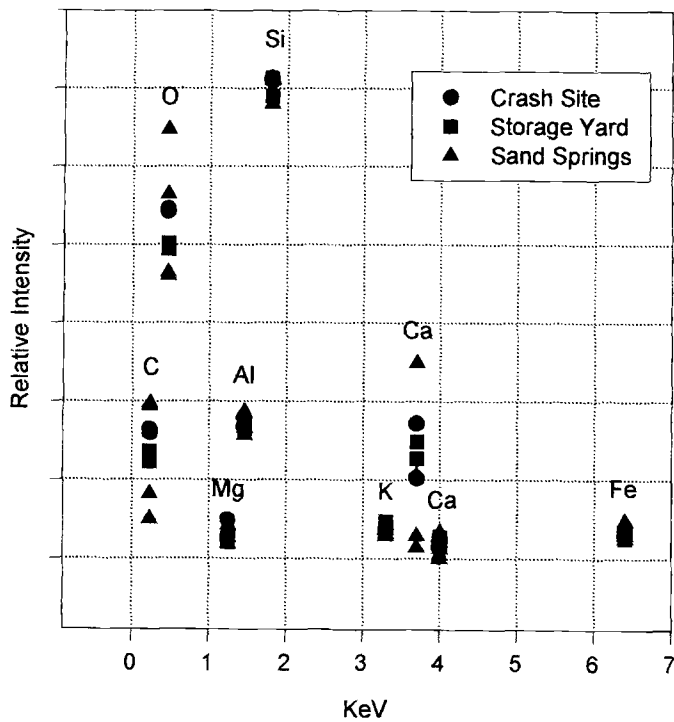


FIG. 10—EDX analysis of eight sample sites compiled and superimposed in one diagram.

by precipitation from water and from microbial activity. Thus, the amount of calcium carbonate in a sample taken from the soil surface can vary with the different seasons depending on how wet or dry the soil is and how much rain has been received in the area recently. The amount of carbon, oxygen, and calcium can vary within a few inches of a sample site. Nonetheless, the plaintiffs used EDX spectra from soil on the lever assemblies to speculate that there was a match between the geologic materials in the soil from Sand Springs, Montana and on the levers.

I also observed a small piece of soil on the side portion of the enrichment, round-edged lever pad. This soil was dark red whereas the rest was lighter gray. One of the major components of soil is iron, and when soil is heated the iron oxidizes and turns the soil red. I postulate that one of the two levers had been burned in a post-crash fire. The lever assembly (part 118) had a charred appearance, and soil on the front of one of the pads was red and melted from intense heat. The post-crash fire was intensive enough to melt the aluminum casting of various parts of the airplane, and aluminum was puddled on the ground at the crash site. This hypothesis is consistent with the results of the heating experiments. As noted, soil samples from the crash site, the storage yard, and from Sand Springs were heated to 1,000°C. As expected, the iron oxidized, and the soil turned red (Table 1). Furthermore, goethite in soil samples can be transformed to maghemite and hematite during fire (12,13), and both enhance the red color of soil even when present in small quantities. A Redness Rating (RR) (14–17) was used to evaluate the reddening of the samples after heating ($RR = (10\text{-YR hue}) \text{ by chroma/value}$). Figure 11 gives the RR values for the samples. As shown, all samples begin to turn red at 500°C which is far below the temperatures of the post-crash fire. No evidence was found for the presence of soil in a pre-crash period that would have interfered with the operation of the airplane.

TABLE 1—Color of soil samples heated to 1,000°C. Sample sites are as follows: 1, crash site; 2 airport storage yard; 3 and 4, Sand Springs, MT.

Temperature °C	Munsell Color			
	Crash Site 1	Storage Yard 2	Sand Springs 3	Sand Springs 4
25	10YR3/3	10YR3/3	10YR3/3	10YR3/3
100	10YR3/3	10YR3/3	10YR3/3	10YR3/3
200	10YR3/3	10YR2/2	10YR2/2	10YR2/2
300	10YR2/2	10YR2/2	10YR2/2	10YR2/2
400	10YR4/3	7.5YR5/4	7.5YR5/4	7.5YR5/4
500	7.5YR5/6	5YR5/6	5YR5/6	5YR5/6
600	5YR5/6	5YR5/6	5YR5/6	5YR5/6
700	5YR5/8	5YR5/8	5YR5/8	5YR5/8
800	2.5YR5/8	2.5YR4/8	2.5YR4/8	2.5YR4/8
900	2.5YR4/8	2.5YR4/8	2.5YR4/8	2.5YR5/8
1000	2.5YR4/8	2.5YR4/8	2.5YR4/8	2.5YR5/8

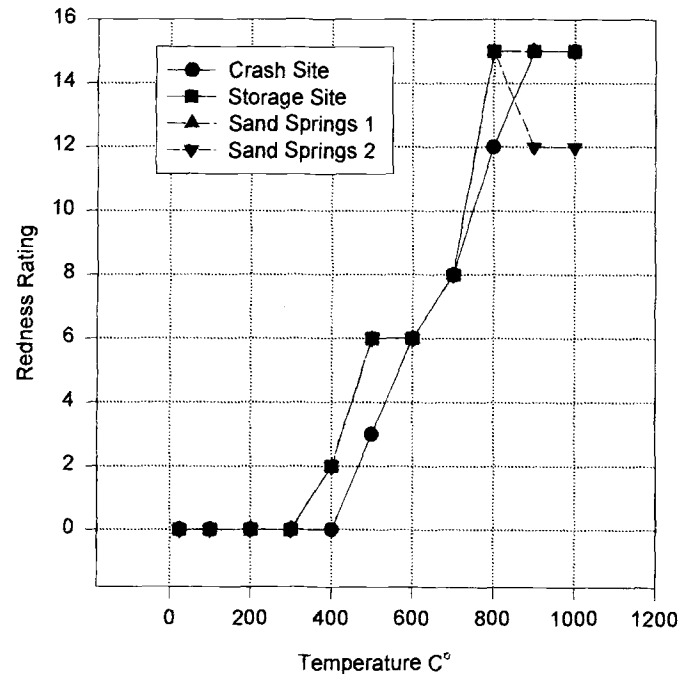


FIG. 11—Redness rating (RR) for eight sample sites.

Acknowledgment

I wish to express appreciation to Kent Voorhees for helping with the EDX analysis.

References

1. Stratton GR. Pedogenetic study of a soil-geomorphic surface age sequence (Master of Science Thesis). Las Cruces: New Mexico State University, 1982.
2. Bailey OF, Daugherty LA, Donart CB. Soil survey of the Fort Stanton experimental ranch—phase I. Las Cruces: New Mexico Agricultural Experiment Station, Special Report No. 43, 1982.
3. Montagne C, Munn LC, Nielsen GA, Rogers JW, Hunter HE. Soils of Montana. Billings: Montana Agricultural Experiment Station, Bulletin No. 744, 1982.
4. Soil Survey Staff. Keys to soil taxonomy. Washington, D.C.: United States Department of Agriculture Soil Conservation Service, 1994.
5. Soil Survey Staff. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Washington, D.C.:

- United States Department of Agriculture Soil Conservation Service, Handbook 436, 1975.
6. Sprankle DG. Soil survey of Lincoln County area, New Mexico. Washington, D.C.: United States Department of Agriculture Soil Conservation Service, 1983.
 7. Jones AA. X-ray fluorescence spectrometry. In: Page AL, editor. Methods of soil analysis: Pt 2, Chemical and Microbiological Properties. Agronomy Monograph No. 9 (Pt 2), 2nd edition. Madison: American Society of Agronomy and Soil Science Society of America, 1982;85–121.
 8. Sawhney BL. Electron microprobe analysis. In: Klute A, editor. Methods of soil analysis: Part 1, physical and mineralogical methods. Agronomy Monograph No. 9 (Part 2), 2nd edition. Madison: American Society of Agronomy and Soil Science Society of America, 1986;271–90.
 9. Munsell Color. Munsell soil color charts. Baltimore: MacBeth Division of Kollmorgen Corporation, 1973.
 10. Soil Survey Division Staff. Soil Survey Manual. Washington, D.C.: United States Department of Agriculture, Handbook 18, 1993.
 11. Bolz RE, Tuve GL. Chemical composition of rocks. In: CRC. Handbook of tables for applied engineering science. Cleveland: CRC Press, 1976;187.
 12. Schwertmann U, Taylor RM. Iron oxides. In: Dixon, JB, Weed SB, editors, Minerals in soil environments, 2nd edition. Madison: Soil Science Society of America, Book Series No. 1, 1989;379–438.
 13. Ulery AL, Graham RC. Forest fire effects on soil color and texture. *Soil Sci Soc America J* 1993;57:135–40.
 14. Schwertmann U. Relations between iron oxides, soil color, and soil formation. In: Bigham JM, Ciolkosz EJ, editors. Soil color. Madison: Soil Science Society of America, Special Publication No. 31, 1993;51–69.
 15. Schwertmann U, Fetcher H. The influence of aluminum on iron oxides: XI. Al-substituted magnemite in soils and its formation. *Soil Sci Soc America J* 1984;48:1462–3.
 16. Torrent J, Barrón B. Laboratory measurement of soil color: Theory and practice. In: Bigham JM, Ciolkosz EJ, editors. Soil color. Madison: Soil Science Society of America, Special Publication No. 31, 1993;21–33.
 17. Torrent J, Schwertmann U, Fetcher H, Alferez F. Quantitative relationships between soil color and hematite content. *Soil Sci* 1983;136:354–8.

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