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Preliminary magnetic, seismic, and petrographic investigations of a possible igneous dike at the Rocky Mountain Arsenal, Denver, Colorado

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Introduction

During the course of geologic consultation at the Rocky Mountain Arsenal, N. P. Timofeef, T.E.S.T., Inc., Boulder, Colo., reported a vertical, east-west-trending tabular body, embedded in fine-grained clastic rocks, that is possibly an igneous dike. The tabular body, about 25 cm thick, crops out in one side of a small borrow pit and extends at least 30 m beyond the pit. The "dike" is slightly harder than the surrounding clastic rocks, which are partly derived from volcanic rocks, and contains minerals that are common to both "intrusive" and extrusive volcanic rocks as well as volcanic-derived sedimentary rocks; its composition opens the possibility that the vertical, tabular body might be either a clastic (sedimentary) dike (Pettijohn, 1975) or an igneous dike. Clastic dikes are usually "slurries" of sediments injected under relatively high hydrostatic pressure induced either by the dynamic pressures of an earthquake or by relatively static pressures. Clastic dikes may also be formed as a filling in a desiccation crack.

If the tabular body is an intrusive igneous dike, its source may possibly be as deep as the basement rocks of Precambrian age, which are about 4 km in depth at the arsenal. The possibility that such an intrusive igneous dike might be continuous upward from the basement to the ground surface concerns the geologists of the Contamination and Migration Branch at the Arsenal. Such a dike might be so impermeable that it could form a lateral barrier to migrating ground water. Conversely, it could be so permeable that it would form an aquifer.

In the spring of 1979, the authors were invited to conduct geophysical surveys in the area in conjunction with other studies. On April 17 and 18, both magnetic and seismic-refraction surveys were performed. In addition, hand samples were examined and tested at the site for magnetic properties, and a map of the area was prepared.

The preliminary geophysical tests showed that the rocks of the dike had neither magnetic nor seismic-velocity contrasts with the surrounding volcanic-rich sedimentary rocks. These data tend to indicate a nonigneous origin for the dike. Furthermore, the authors are not aware of any igneous intrusions in the Denver area that are more than a few kilometers east of the mountains and this would suggest that the dike seems to be out of its geologic environment. Petrographic evidence described by D. S. Collins, F. M. Byers, Jr., and others of the USGS (U.S. Geological Survey), however, indicates that the dike is of volcanic igneous origin, but we submit that the petrographic evidence can also be duplicated by a clastic dike. We, therefore, tentatively conclude that the body is a clastic dike.

Stephen P. Kanizay of the USGS aided the surveys on a part-time basis and both Kanizay and R. P. Hoblitt, USGS, provided guidance. Witnesses to the surveys included B. L. Anderson, Gregory Ward, and W. Trautmann of the Contamination and Migration Branch of the U.S. Army staff at the Arsenal; F. Bopp of the U.S. Army Corps of Engineers, Waterways Experiment Station, at Vicksburg, Miss.; and J. C. Romero of the Water Resources Division of the State of Colorado.

The site

Figure 1 shows the site of the possible dike; the dike is located in the center of sec. 35, T. 2 S., R. 67 W., in the Sable quadrangle. The dike is about 25 cm thick, is essentially vertical, and strikes nearly due east. It is exposed on the east side of the borrow pit and can be traced eastward for about 30 m.

Bedrock in the site area consists of a fine-grained, calcareous sandstone, some of which is tuffaceous, as well as siltstone, shale, and claystone of the Denver (Paleocene and Upper Cretaceous) and Arapahoe (Upper Cretaceous) Formations. The bedrock is capped by Verdos Alluvium (Pleistocene), consisting of a poorly sorted gravel that contains lenses of clay, silt, and sand. Much of the Verdos Alluvium and some of the bedrock has been excavated at the borrow pit. A thin veneer of windblown sand and silt may overlie either or both the Verdos Alluvium and bedrock.

EXPLANATION

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Topographic contour; interval is 1 m; dashed where estimated; low areas are hachured. Base is estimated from U.S. Geological Survey map.

0 20 40 60 meters

Line A

Magnetic-data lines (A–D), meters. Seismic refraction data was also run from 0-40 m, Line A, and along Line E (9 m in length), which is on the "dike."

▫ 1X,1XX,2X,3X,3XX,4X,5X, and 6X

Hand sample for magnetic measurements

● A,B,C, and D

Petrographic thin section

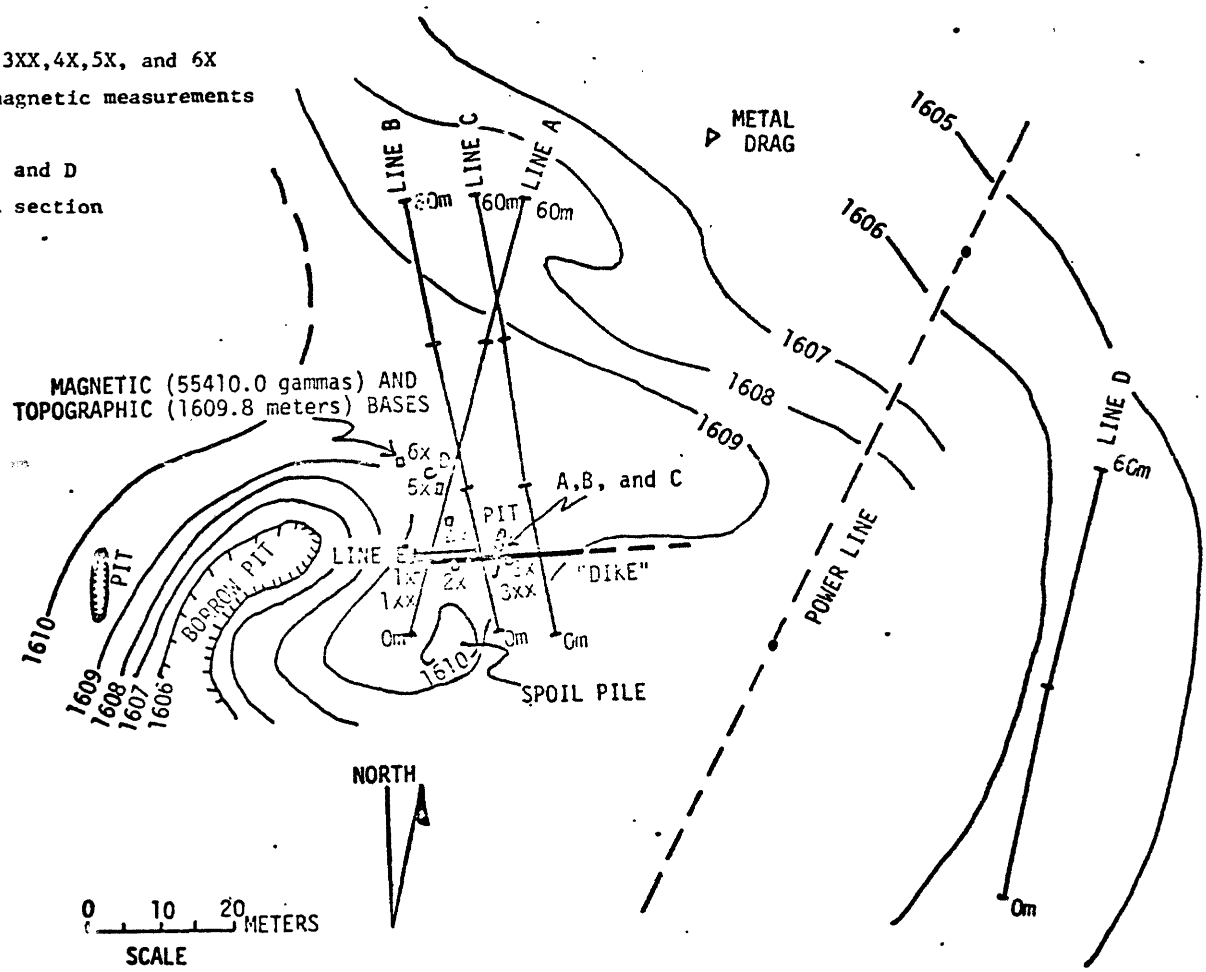


Figure 1. --Topographic map and location of data points and lines at the site of a possible dike, Rocky Mountain Arsenal, Denver, Colorado.

The authors are not aware of any igneous intrusions in the Denver area that are more than a few kilometers east of the mountains. Harms (1965) reported clastic dikes which are associated with major reverse faults along the Rocky Mountain Front. The dikes trend north with generally the same strike and dip as the Laramide faults, and the dikes are, therefore, probably also Laramide in age. The dikes are mostly emplaced in rocks that are Precambrian in age. The dikes are composed of nearly pure quartz sandstones whose composition closely resembles the friable Cambrian Sawatch sandstone, which is stratigraphically many thousands of feet below the ground surface. Granite fragments and quartz grains in the dikes are well oriented with their long axes lying parallel to the dip directions of the dikes. Harms concludes that the grain orientation definitely precludes filling by gravity fall of individual grains into an open fissure.

Magnetic surveys

A survey of total magnetic intensity was conducted using a portable proton magnetometer along lines A-D (fig. 2). Readings were recorded at 1-m intervals with the sensor at a constant height of about 2.1 m above the ground. Individual readings of total magnetic intensity were obtained to an accuracy of about ±1 gamma (1 nanotesla). The data were converted to a base value of 55,410.0 gammas, which is representative of the field at the site. Base readings were repeated within 15 minutes of the initial reading at an accuracy of ±2 gammas, and this base drift was linearly distributed over the station readings.

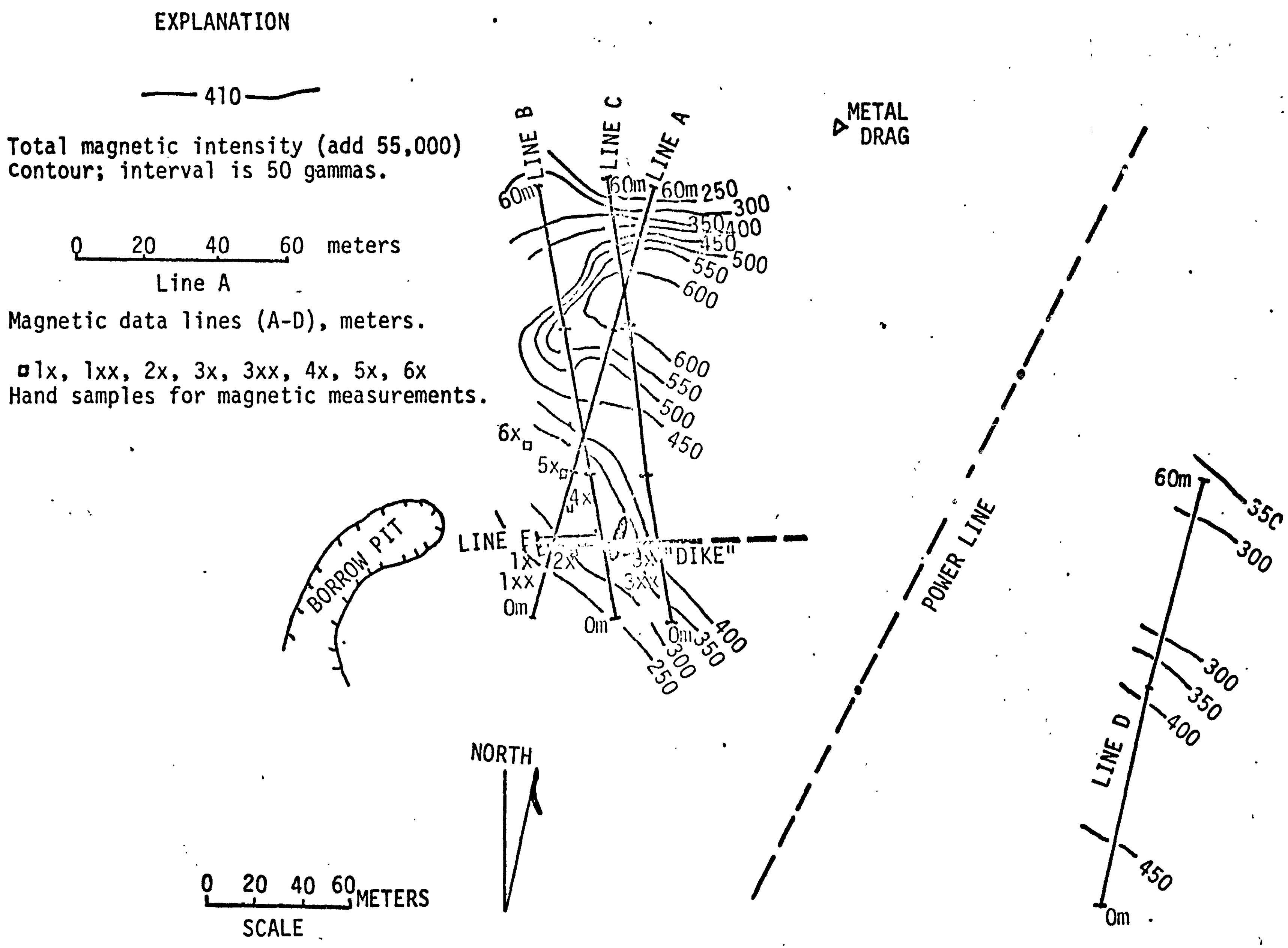


Figure 2.--Total magnetic intensity map of the site around a possible dike.

The maximum magnetic change along the collective lines A-C is about 350 gammas within a distance of 15 or 20 m. There is no indication, however, that the dike is influencing the magnetic field. On the contrary, the gradients are nearly parallel to the strike of the dike, whereas the gradients would be more perpendicular to it if the dike were influencing them. There is a magnetic anomaly along line D at about where the dike is projected, but the anomaly is about a 150-gamma low, compared to the rest of line D. An igneous dike is expected to produce a positive anomaly.

The maximum magnetic anomalies at the site are (1) at the intersection of lines B and C, and (2) on line D at about 30 m. Each of these anomalies can presumably be explained by relatively rapid lateral changes in magnetite content in the many lenses of the Denver and Arapahoe Formations. Measurements of the magnetic susceptibilities of host rock samples yielded values that range from 10^{-6} to nearly 10^{-3} cgs. Lateral susceptible contrasts of this magnitude at the edge of a "horizontal slab of relatively great thickness and breadth," for example, would produce an anomaly of about 350 gammas (Briener, 1973, p. 28).

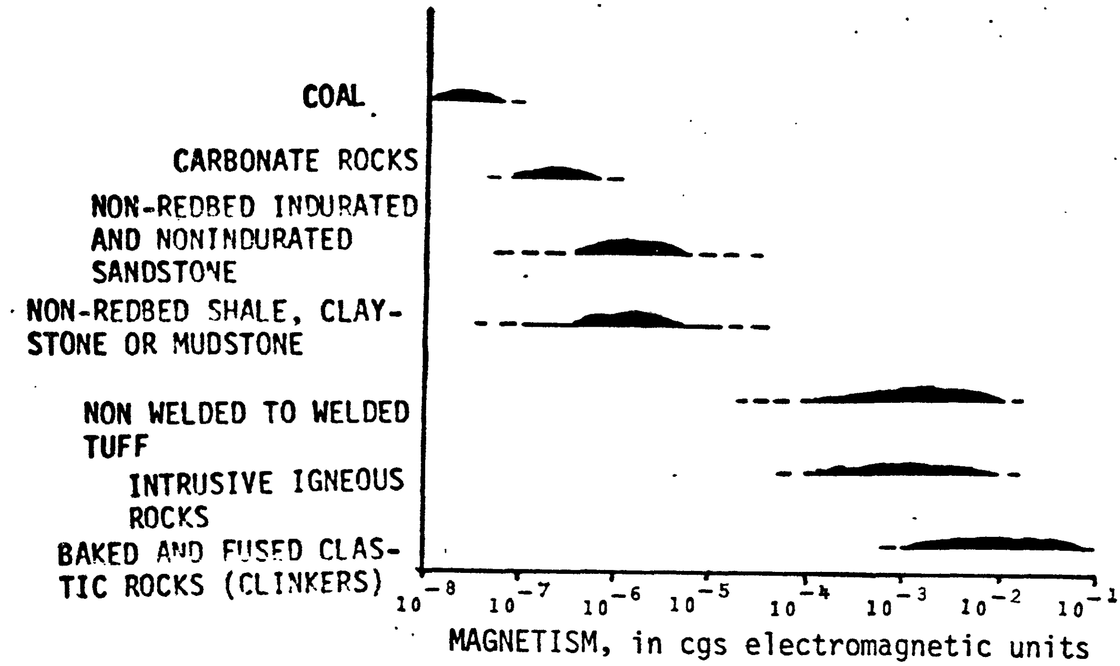
Tests for magnetism were performed on the hand samples from the locations indicated by figure 2. The tests were done with the same portable magnetometer used in the ground magnetic survey, using techniques described by Briener (1973). These techniques do not have the precise controls of a laboratory measurement, but the sample sizes are relatively large and we believe the accuracy of the field measurements may approach those made in the laboratory.

The magnitude of the remanent and induced magnetism and magnetic susceptibilities of the dike rocks are compared with those of the "nondike" rocks in figure 3b. There is little difference in the range of magnetism or of susceptibilities between the two lithologies. The magnetization and susceptibility of each rock type range from 10^{-6} to 10^{-3} cgs units, but most are about 10^{-5} cgs units.

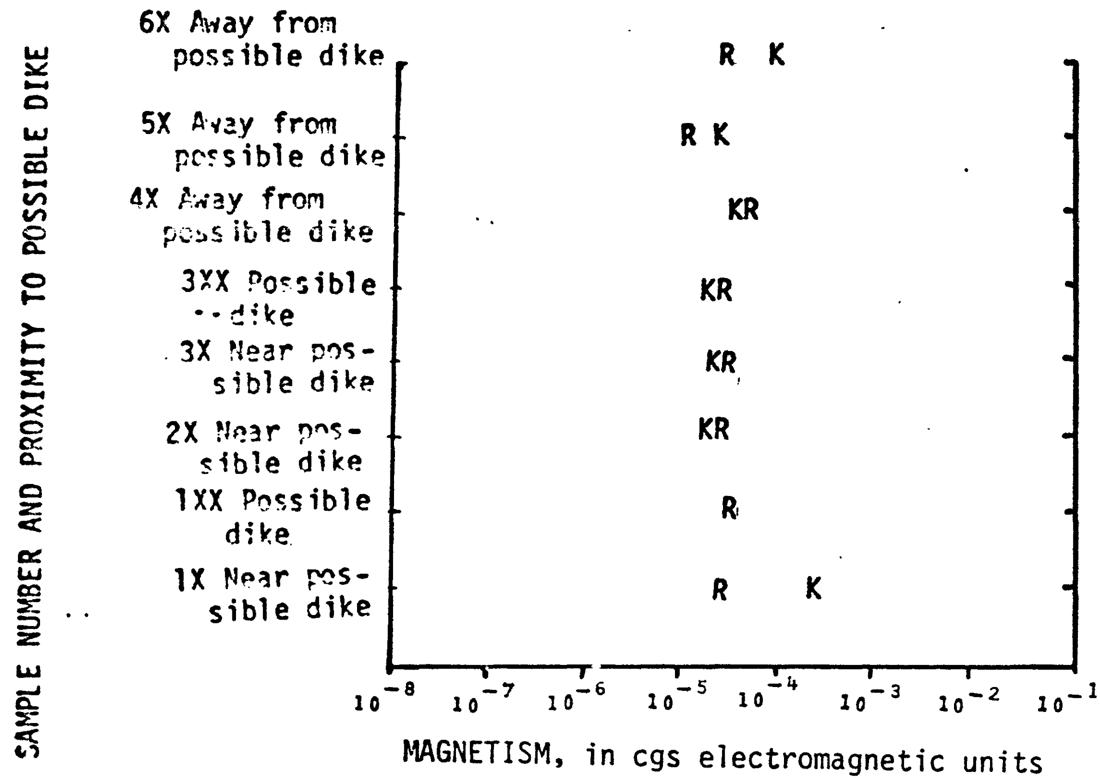
The magnitudes of remanent and induced magnetism of the sedimentary rocks at the Arsenal (fig. 3b) are also plotted along with representative values of net magnetism of various other rock types (fig. 3a). Remanent and induced magnetism are components of net magnetism, but the directions of the magnetism of the rocks at the Arsenal are unknown and they are, therefore, only approximately comparable with the representative net magnetism of the rocks shown in figure 3a. Any combination of measurements of remanent and induced magnetism of the rocks at the Arsenal site is about midway between the net magnetism shown for clastic rocks and that for the nonwelded tuffs of figure 3a. These preliminary magnetic data show that the dike rocks do not exhibit the level of magnetism associated with intrusive igneous rocks.

Seismic survey

Figure 4 shows the traveltime graphs and velocities of three seismic lines that were surveyed over the dike. Two of the lines are each 20 m long and together they constitute 40 m of line A (fig. 1), which is 60 m long. These two lines are essentially perpendicular to the dike. The third seismic line (line E of fig. 1) is 9 m long on top of the dike and parallel to its strike. Background noise from aircraft, nearby industry, and winds gusting to 60 km/h hampered the survey of all three seismic lines.



(a.) Representative net magnetism of various rock types (D.E. Watson, unpublished data, Nov. 1976)



(b.) R, remanent magnetization, induced magnetization, and K magnetic susceptibility.

Figure 3.--The magnetism of hand samples of a possible dike and of the surrounding sedimentary rocks compared to representative net magnetism of various rock types.

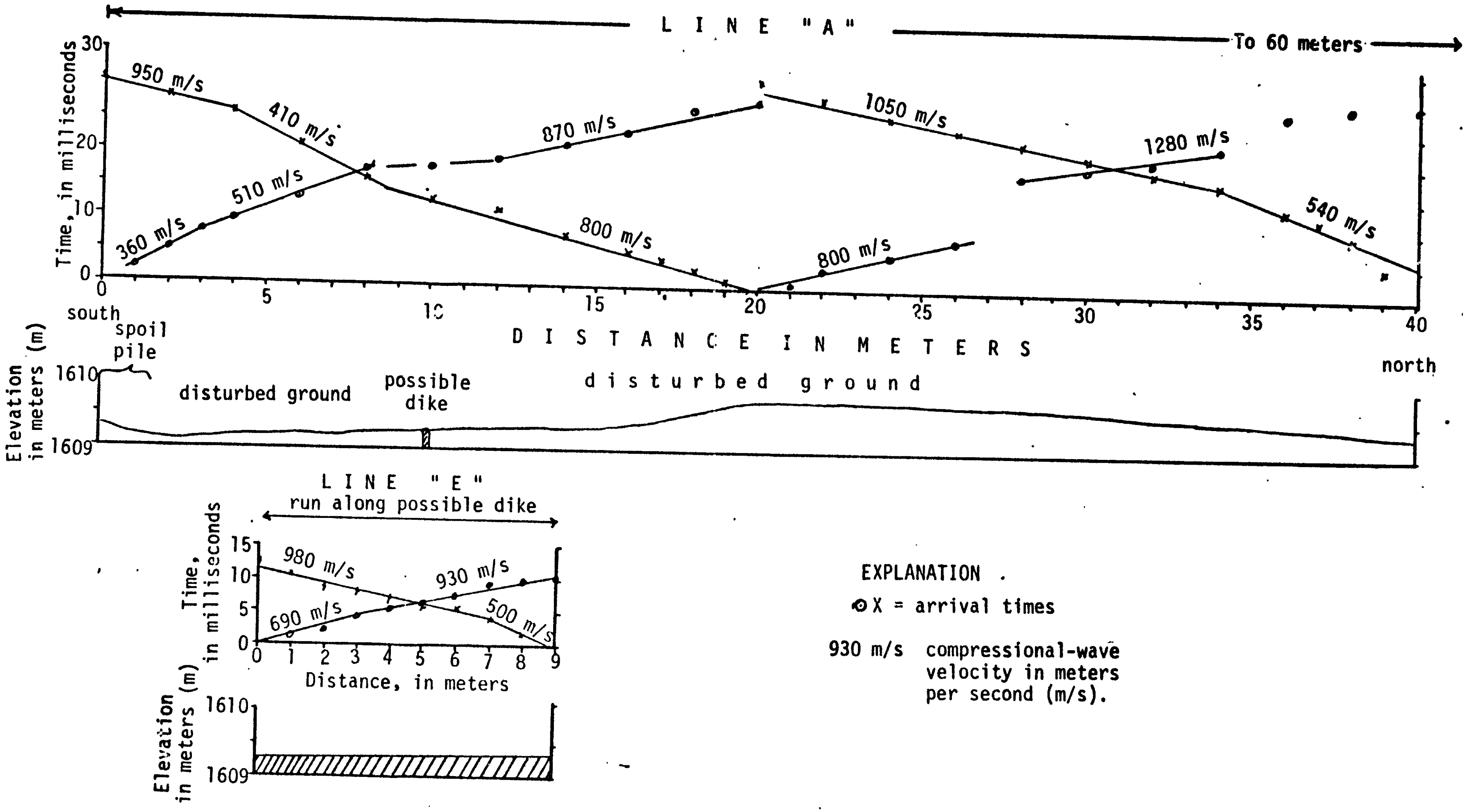


Figure 4. Seismic compressional-wave velocity lines' run over a possible dike (fig. 1).

Seismic velocities at the site range from about 360 to 1280 m/s. The seismic line that extends from 0 to 20 m along line A exhibits nonuniform velocities that are probably attributable to disturbed ground and topographic relief rather than to the influence of the dike. The maximum velocities of the dike rocks along line E average about 950 m/s. These velocities of the dike rock are about intermediate in the whole range of velocities at the site and no seismic-velocity contrast is apparent between the dike and the clastic rocks.

The compressional-wave velocities of clastic rocks at the Arsenal site are compared to the velocities of other clastic rocks, both in the Powder River Basin of Wyoming and in other areas away from the basin (Miller, 1979), in figure 5. The velocities obtained for clastic rocks at the Arsenal site are most similar to those of the "low-velocity" layer of near-surface clastic rocks (Tertiary in age) in the Powder River Basin. The seismic velocities of the dike rocks are rather low compared to those of volcanic tuffs in figure 5.

Petrographic analysis

Three thin sections of the dike rock and one of the clastic rocks at some distance from the dike were examined by D. S. Collins and F. M. Byers, Jr., of the USGS. The rock types interpreted from each thin section are summarized in table 1, and the sample numbers are keyed to locations shown in figure 1. Byers believes the dike rocks were emplaced from an igneous source. Because of strong parallel orientation of mica crystals, he also believes that the rocks were transported in a liquid-crystal phase. He concedes, however, that parallelism could, perhaps, also be attained by waterborne mica grains from a source bed of tuff at depth and under high hydrostatic pressure.

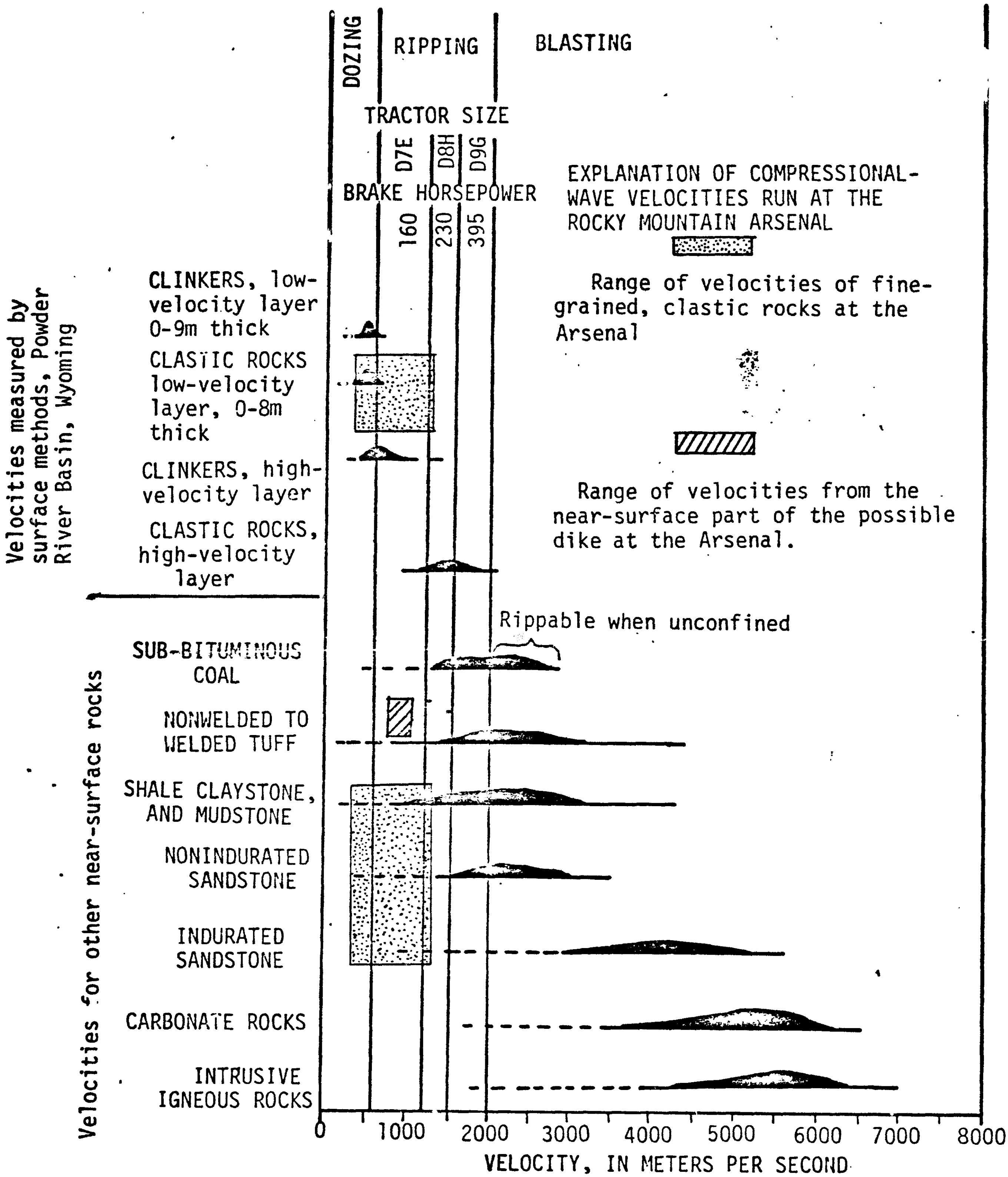


Figure 5. Seismic compressional-wave velocities run over a possible dike at the Rocky Mountain Arsenal, Denver, Colorado, compared to compressional-wave velocities and estimated economical dozing, ripping, and blasting capabilities of various rock types (▲ nonweathered, ---- weathered). Data from other than at the Arsenal is from surface measurements in the Powder River Basin, Wyoming, from literature, and from estimates.

Table 1.--Identification of rock types and their constitutent minerals interpreted from thin sections

[Identified by D. S. Collins, F. M. Byers, Jr., and others, U.S. Geological Survey; --- no data]

Sample no.	In situ location[1]	Rock type	Mineral Constituents												
			Ground mass	Total lithics	Quartz	Alkalic feldspar	Plagioclase	Biotite	Opaque	White mica	Horn-blende	Apatite	Clino-pyroxene	Carbonate	Other
A	Within 0.15 m of dike.	Rhyodacite lava or volcanic intrusive.	50	---	---	---	40	---	3	---	5	1	1	---	---
B	At dike-------	Quartz latite tuff.	60	1	1	5	10	10	1	10	1	---	---	---	1
C	At dike-------	Quartz latite tuff.	60	1	1	5	10	10	1	10	1	---	---	---	1
D	Ten m from dike.	Calcareous sandstone.	---	---	---	---	15	---	---	---	---	---	---	85	---

[1]Figure 1.

Summary and conclusions

A vertical, tabular body embedded in fine-grained, tuffaceous, calcareous sandstones, siltstones, and shales has been reported at the Rocky Mountain Arsenal. The tabular body has the mineralogy and structure of an igneous dike, but it may also be a clastic dike of sedimentary origin. The possibility that the body may be an igneous dike is of concern to the staff geologists at the Arsenal because it could extend to great depth and be impermeable enough to provide a barrier to laterally migrating ground water or, conversely, it could be relatively permeable and provide an aquifer.

Hand samples were tested in the field for magnetic properties. The results indicated no appreciable magnetic contrast between the dike and surrounding volcanic-rich clastic rocks. This range of magnetic properties for either rock type is about intermediate between the magnetism of sedimentary and tuffaceous rocks, but the range is below the level of magnetism associated with intrusive igneous rocks. Magnetic surveys were also conducted over the dike, but no magnetic anomalies were associated with the dike. Anomalies that were found away from the dike are thought to be caused by the lateral and near-surface variations in magnetite concentration associated with the many lenses present in the clastic rocks.

Seismic-velocity surveys were also conducted both over the dike and away from it. These preliminary near-surface velocity surveys indicate no velocity contrast between the dike and surrounding clastic rocks. Any of the velocities that were measured at the site are more typical of a weathered layer of clastic rocks than of the nonweathered layer. The seismic velocities of the dike are rather low when compared to representative velocities of nonweathered volcanic tuffs and very low compared to velocities of intrusive igneous rocks.

Not only do the magnetic and seismic data indicate that the dike is not an intrusive igneous body, but an igneous dike would seem to be out of its geologic environment at the Arsenal. The authors are not aware of any reports of intrusive igneous bodies that far east from the mountains and in the Denver area. Nevertheless, there is strong petrographic evidence that the dike is of a volcanic igneous origin because of its mineral constituents and parallelism of its grains. We submit, however, that these petrographic parameters can be duplicated by a clastic dike. Previously deposited volcanic-rich sediments from below could conceivably have been mobilized by pore-water pressures that exceeded overburden pressures and these sediments could have been emplaced upward into a vertical fracture. We tentatively conclude that the tabular body is a clastic dike, but that further evidence must be presented before final conclusions can be drawn.

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