U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES MAP MF–2353
Version 1.0
PAMPHLET

GEOLOGIC MAPS AND CROSS SECTIONS OF MINE LEVELS AT THE PEA RIDGE IRON MINE, WASHINGTON COUNTY, MISSOURI

By

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2001

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INTRODUCTION

This geologic mapping and interpretation of the Pea Ridge iron mine, Missouri, is part of a cooperative effort between the U.S. Geological Survey (USGS) and the Missouri Department of Natural Resources, Division of Geology and Land Survey (DGLS), under the auspices of the USGS Midcontinent Strategic and Critical Minerals Project. The goal of the Pea Ridge study is to compare the Middle Proterozoic iron deposits of Missouri with the Middle Proterozoic Olympic Dam deposit and similar deposits of the Stuart Shelf, South Australia. This effort developed from work by Sims and others (1987), who recognized the many similarities between the St. Francois terrane in southeastern Missouri and the Stuart Shelf and also the potential for Olympic Dam-type deposits in the Middle Proterozoic granite-rhyolite terranes of the Midcontinent. Detailed descriptions of the map units are given in Nuelle and others (1992). Results of stable-isotope, fluid-inclusion, and trace-element studies that focus on the origin of the ore deposit are presented in Day and others (1991, 1992, and 1993), Sidder and others (1991, 1993a, b), and Cordell and others (1993).

The Pea Ridge Iron Ore Company granted access to the mine for purposes of geologic mapping and for topical studies to determine ore genesis and to investigate the potential for mineral commodities other than iron, such as rare-earth elements and gold. Additional information for underground areas and mine levels was obtained from generalized maps and logs of developmental drill core by the late Jack Emery, former mine geologist with the Pea Ridge Iron Ore Company. Mine level designations are those used by the company; sublevels indicate workings accessible only by declines from other levels. All levels are measured in depth from the shaft collar.

MAP UNITS

Map units outlined in this report are based in part on those of Emery (1968). Nuelle and others (1992) characterized the units in detail and described their modes of origin. The main

map units are amphibole-quartz rock, heterolithic breccia, pseudobreccia, magnetite, hematite, silicified rock, rare-earth-element (REE) mineral-bearing breccia pipes, mafic dikes, and aplite dikes (Nuelle and others, 1992). A new rock unit, the iron oxide-cemented amphibole breccia, defined during the compilation of these maps, is known only from Emery's descriptions of drill core. All iron oxide-cemented breccias have been subdivided according to the type of iron oxide (magnetite or hematite) cement and further subdivided by ore grade. An ore-grade cutoff of 37 percent magnetic iron (Larry Tucker, Pea Ridge Iron Ore Company., oral commun., 1992) is used to define ore and non-ore units.

Individual unit descriptions are based primarily on the mineral assemblages and character of the rock or ore type. Brief genetic discussions are included as needed to clarify relations between units. Those interested in further discussions of genesis of the deposit are referred to Sidder and others (1993a) and Nuelle and others (1991, 1992).

DESCRIPTION OF MAP UNITS

€l **Lamotte Sandstone (Upper Cambrian)**—White, well-sorted quartz sandstone and basal conglomerate directly overlying Precambrian sequence (noted at 1,375-ft level). Quartz sandstone is Upper Cambrian Lamotte Sandstone. Underlying conglomerate mapped together with unit €l. Age of conglomerate is not definitely known; may span from Middle Proterozoic to Late Cambrian

MIDDLE PROTEROZOIC UNITS

da **Aplite dikes**—Aplitic to pegmatitic dikes consisting of potassium feldspar and quartz with minor to trace amounts of biotite and traces of disseminated molybdenite. The aplitic to pegmatitic dikes are alaskitic in composition and high in silica (72.0–74.7 weight percent SiO_2) and potassium (6.7–9.8 weight percent K_2O). Aplite dikes fill fractures that strike N. 25° W. and dip steeply to flatly to the northeast (Emery, 1968). Aplite dikes cut host rhyolite, magnetite orebody, silicified rock, and mafic dikes; contact with rare-earth-element (REE) mineral-bearing breccia pipes not observed. Trace-element modeling demonstrates that aplite dikes and host rhyolite are cogenetic (Day and others, 1989)

dm **Mafic dikes**—Black to dark-greenish-gray rocks having a greasy luster and blocky cleavage. Intense chloritic alteration partially obscures original composition, but data on major and trace elements indicate that dikes are tholeiitic basalt (W.C. Day, unpub. data, 1990). Locally, some dikes are brecciated and cemented by late calcite. Thickness ranges from less than 1 cm to more than 3 m. Dikes intruded two fracture systems, which strike N. 60° E. and N. 85° W. and dip 60°–80° SE. and SW., respectively. Mafic dikes cut host rhyolite, magnetite orebody, and silicified rock; contact with the REE mineral-bearing breccia pipes not observed. Dashed where projected or inferred

bp **REE mineral-bearing breccia pipes**—Fragments of rhyolite, iron oxide, and silicified rock in a groundmass of rock flour, feldspar, chlorite, barite, apatite, monazite, xenotime, quartz, and calcite. Volcanic rock fragments range from less than 1 mm to about 0.5 m in diameter, are subrounded to angular with moderate to high sphericity, and have undergone potassium metasomatism. Specularite fragments are angular, are as long as several meters, and have low to moderate sphericity. REE mineral-bearing minerals include monazite, xenotime, and rare bastnaesite and britholite. Monazite and xenotime occur as radial crystal aggregates and granular crystals (0.5–1.9 mm); they also replace wall-rock microfragments and fill fractures in barite and potassium feldspar crystals in groundmass (Nuelle and others, 1992). Total REE oxide concentrations of grab samples range from about 2.5 to 19 weight percent. U.S. Bureau of Mines bulk samples range from 7 to 25 weight percent and average 12 weight percent (C.W. Vierrether, U.S. Bureau of Mines, oral commun., 1990). Four pipes have been delineated along the footwall and eastern edge of orebody. They occur at or near contacts between major lithologic zones and may have been emplaced along zones of weakness created by faults. Contacts of pipes with wall rock and hematite are commonly irregular; some contacts are embayed. Apophyses of pipe material locally intrude volcanic rocks, mas-

sive magnetite, magnetite-cemented breccias, hematite, hematite-cemented breccias, and silicified rock. The pipes are steeply dipping (greater than 60°) and elongate to ovoid in plan view. Horizontal length is as much as 60 m; widths reach as much as 15 m. Their maximum vertical extent is unknown, but one pipe extends a minimum of 120 m. Breccia pipes not intersected in drifts or drill cores are interpolated from three-dimensional modeling (Seeger, 1992) and are indicated by dashed lines

sr **Silicified rock**—Characterized by massive, white to light-gray quartz that replaced host rhyolite with varying intensity; areas with greater than 75 percent quartz are common. Potassic alteration characterized by addition of potassium feldspar to both silicified rock and surrounding wall rock is commonly associated with silicification. Quartz and potassium feldspar form local pegmatitic pods and veins. Accessory minerals include fluorite, muscovite (and sericite), biotite, tourmaline, chlorite after biotite, epidote, monazite, apatite, topaz, calcite, barite, rutile, zircon, hematite, pyrite, and chalcopyrite. Sericite is especially common along fracture and fragment surfaces. Silicification and potassic alteration are extensively developed in footwall of orebody, although they are found throughout mine. Horizontal underground drilling away from orebody on 2,275-ft level penetrated 120 m without exiting silicified rock; surface drill holes more than 400 m north of footwall of orebody intersected silicified volcanic rock. Silicified rock is a product of both open-space filling and replacement; it contains relict breccia textures, which suggests that brecciated zones acted as conduits for silica- and potassium-rich fluids (Seeger and others, 1989). Map units that are only slightly silicified are denoted by a dotted pattern

h **Specular hematite**—Finely to coarsely crystalline, generally platy, massive specular hematite. Constitutes a major part of iron oxide body in uppermost mined levels, eastern footwall, and eastern margin of orebody. Width varies from about 400 ft where it covers top of orebody to less than 25 ft at deeper levels. Contacts between hematite and magnetite are commonly gradational; hematite commonly contains irregularly distributed patches and areas of magnetite. Hematite (as martite) is primarily an alteration product after magnetite. It formed in part along fault zones and is locally sheared and foliated parallel to post-ore faults. On uppermost mined levels, martite may be result of oxidation by meteoric water and groundwater

hu **Hematite, undivided**—Massive hematite and (or) hematite-cemented breccias. Exposed only on several of the lower levels of the mine

m **Magnetite**—Dark-gray, fine-grained, massive to brecciated magnetite. Map unit characterized by containing 58 percent or more magnetic iron and (or) less than 20 percent clasts. Gangue minerals form interstitial intergrowths, net-textured veinlets, and pods within the ore, and include apatite, quartz, and phlogopite with minor amphibole, chlorite, pyrite, fluorite, barite, calcite, chalcopyrite, and monazite, and traces of grunerite, talc, and other minerals. Texture varies from massive and shiny with subconchoidal fracture to finely crystalline and granular. Some ore has a porphyritic texture, consisting of magnetite (or martite) and hematite (specularite) megacrysts in a massive, fine-grained groundmass of magnetite. Magnetite is commonly brecciated and cemented by barite and calcite near REE mineral-bearing breccia pipes (unit bp). Magnetite is the only ore mineral recovered at Pea Ridge. Ore faces contain as much as 90 volume percent magnetite, and ore grade averages about 55 percent magnetic iron (Emery, 1968). Ore grade cutoff is about 37 percent magnetic iron

Pseudobreccia—Pseudobreccia is defined as host volcanic rock that is partially replaced by magnetite (units mpbn and mpbo) and (or) hematite (unit hpb) along preferred fracture planes, giving a breccialike appearance; fragments are not rotated or mechanically fragmented (Nuelle and others, 1992). In regions where hydrothermal solutions have replaced large parts of the host volcanic rocks, the pseudobreccia is recognized as isolated islands of porphyry surrounded by iron oxide. Host rhyolite fragments have irregular boundaries, contain embayments of iron oxide, and may have a wispy or stringy shape after extreme replacement. Pseudobreccia contains at least 10 percent iron oxide matrix and at least 20 percent clasts. Unit is found on margins of orebody, and is most common in footwall. Roundness and potassium metasomatic alteration of fragments as well as the percentage of iron oxide matrix increase towards orebody. The three mappable textural variants of pseudobreccia are:

mpbn **Magnetite-cemented pseudobreccia non-ore**—Unit contains less than 37 percent magnetic iron as matrix cement; unit is below ore grade

mpbo **Magnetite-cemented pseudobreccia ore**—Unit is defined as containing between 37 and 58 percent magnetic iron

hpb **Hematite-cemented pseudobreccia**—Matrix material dominated by hematite

Iron oxide-cemented heterolithic breccia—Fragments of host rhyolite, chloritized rhyolite, and amphibole-quartz rock in matrix of magnetite (units mhbn and mhbo) or hematite (unit hhb). Clast size for each variety ranges from several centimeters to greater than 4 m in diameter; clasts are generally angular to subrounded in shape. Relative percentages of clast types vary widely, some mine faces contain only one or two lithologic types; total clast percentages range as high as 30 percent. Clast abundance decreases near contacts with massive magnetite and increases near contacts with amphibole-quartz rock or with host volcanic rocks; all contacts are gradational. Extent of chloritization and magnetite replacement of rhyolite clasts varies. Amphibole fragments commonly contain a quartz core, and actinolite crystals radiate perpendicular to the fragment's margin, which suggests that some amphibole alteration is post-brecciation. Breccia occurs discontinuously along margins of orebody and is particularly well developed along hanging wall

mhbn **Magnetite-cemented heterolithic breccia non-ore**—Unit is defined as having less than 37 percent magnetic iron in the matrix material

mhbo **Magnetite-cemented heterolithic breccia ore**—Map unit contains between 37 and 58 percent magnetic iron in the matrix material

hhb **Hematite-cemented heterolithic breccia**—Matrix material dominated by hematite

Iron oxide-cemented amphibole breccia—Clasts of amphibole-quartz rock (unit aqr) in matrix containing greater than 10 percent magnetic iron (or minimum of 15 percent total iron oxide); extent of unit is known only from core log descriptions by J.A. Emery (Pea Ridge Iron Ore Company, unpub. data, 1995)

mabn **Magnetite-cemented amphibole breccia non-ore**—Unit is defined as having less than 37 percent magnetic iron in the matrix material

mabo **Magnetite-cemented amphibole breccia ore**—Map unit contains between 37 and 58 percent magnetic iron in the matrix material

hab **Hematite-cemented amphibole breccia**—Matrix material dominated by hematite

mbu **Magnetite-cemented breccia, undivided**—Unit used in areas with limited information to delineate if the matrix is either magnetite- or hematite-dominant. Shown only on maps of several of the lower levels (2,370, 2,440, 2,505, and 2,675 ft)

aqr **Amphibole-quartz rock**—Massive, coarse-grained actinolite blades as long as 5 cm intergrown with quartz and lesser amounts of apatite, magnetite, pyrite, chalcopyrite, and calcite. Quartz forms massive pods 1–50 cm in diameter. In the hanging-wall area of the ore deposit, unit is brecciated and cemented by iron oxide veins. In the footwall area, unit shows less brecciatation and contains less quartz. Massive amphibole-quartz rock in eastern end of hanging wall thins westward into actinolite-filled fractures that have silicified margins in host rock (Emery, 1968). Locally, unit grades into host rhyolite wall rock showing incipient amphibole alteration. Amphibole-quartz rock found in both hanging wall and footwall is result of hydrothermal alteration front that temporally preceded magnetite emplacement. Textural and chemical evidence of original host rock type has been partly to completely destroyed by metasomatic replacement, although relict rhyolite wall-rock textures have been noted in amphibole-quartz clasts in hanging wall (J.R. Husman, The Doe Run Company, oral commun., 1990). Regions that contain minor amphibole alteration are mapped by a random pink pattern

vr **Volcanic rocks**—Rhyolitic ash-flow tuffs. Porphyritic rhyolite tuff generally has aphanitic tuffaceous groundmass of quartz and orthoclase, and contains orthoclase phenocrysts. Several ash-flow tuffs contain well-developed collapsed pumice fragments; one unit contains angular lithic fragments having no preferred orientation. Oldest volcanic rocks are in hanging wall; they become progressively younger northward (Husman, 1989). Average strike of volcanic sequence is N. 80° W., dipping 75°–90° NE.

br **Banded rock**—Alternating bands of light-gray (igneous rock fragments, quartz, and potassium feldspar) and dark-gray (martite and chlorite) rock ranging from 1 mm to several centimeters in thickness. Restricted to footwall near hematite-silicified wall rock con-

tacts on 2,275-ft level where unit grades into specular hematite, which suggests that it was part of host rock sequence that was variably replaced by iron oxide. Unit may represent altered horizons in a bedded volcaniclastic sedimentary sequence. Protolith was probably water-laid tuff incorporated into volcanic sequence (Nuelle and others, 1992)

ACKNOWLEDGMENTS

The authors would like to acknowledge the staff of the Pea Ridge Iron Ore Company for allowing access to the mine and company data, without which these maps could not have been completed. Special thanks are offered to Larry Tucker and Don Roberts of the Pea Ridge Iron Ore Company for their cooperation in making this project possible. Laura Tressler at DGLS spent many hours at the digitizer preparing these maps for production. Warren Day (U.S. Geological Survey) provided unpublished geochemical data, helped formulate concepts on the origin of the map units, and processed the map through the publication procedure.

REFERENCES CITED

Cordell, Lindrith, Sidder, G.B., and Day, W.C., 1993, Aeromagnetic constraints on shape of parent magma source at Pea Ridge, Missouri, magnetite mine: Geological Society of America Abstracts with Programs, v. 25, no. 3, p. 14.

Day, W.C., Kisvarsanyi, E.B., Nuelle, L.M., Marikos, M.A., and Seeger, C.M., 1989, New data on the origin of the Pea Ridge iron-apatite deposit, southeast Missouri—Implications for Olympic Dam-type deposits: Geological Society of America Abstracts with Programs, v. 21, no. 6, p. A132.

Day, W.C., Sidder, G.B., and Kisvarsanyi, E.B., 1993, Petrogenetic controls on the formation of Middle Proterozoic iron–copper–rare-earth-element deposits of Missouri: Geological Society of America Abstracts with Programs, v. 25, no. 3, p. 16.

Day, W.C., Sidder, G.B., McCafferty, A.E., Cordell, L.E., Kisvarsanyi, E.B., Rye, R.O., and Nuelle, L.M., 1991, Origin of iron, rare-earth elements, copper, and gold in Middle Proterozoic deposits of the midcontinent region, U.S.A., *in* Good, E.E., Slack, J.F., and Kotra, R.K., eds., U.S. Geological Survey Research on Mineral Resources, 1991, Program and Abstracts: U.S. Geological Survey Circular 1062, p. 16.

Day, W.C., Sidder, G.B., Rye, R.O., Nuelle, L.M., and Kisvarsanyi, E.B., 1992, The Middle Proterozoic rhyolite-hosted Pea Ridge iron and rare-earth-element deposit—A magmatic source for Olympic Dam-type deposits in the midcontinent region of the U.S.A. [abs.], *in* Brown, P.E., and Chappell, B.W., eds., Second Hutton Symposium; The origin of granites and related rocks: Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 83, part 2, p. 489.

Emery, J.A., 1968, Geology of the Pea Ridge iron ore body, *in* Ridge, J.D., ed., Ore deposits of the United States, 1933–1967: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers (Graton-Sales Volume), v. 1, p. 359–369.

Husman, J.R., 1989, Gold, rare earth element, and other potential by-products of the Pea Ridge iron ore mine: Missouri Department of Natural Resources, Division of Geology and Land Survey, Contributions to Precambrian Geology No. 21, Open-File Report OFR–89–78–MR, 18 p.

Nuelle, L.M., Day, W.C., Sidder, G.B., and Seeger, C.M., 1992, Geology and mineral paragenesis of the Pea Ridge iron ore mine, Washington County, Missouri—Origin of the rare-earth-element- and gold-bearing breccia pipes, *in* Day, W.C., and Lane, D.E., eds., Strategic and critical minerals in the Midcontinent region, United States: U.S. Geological Survey Bulletin 1989–A, p. A1–A11.

Nuelle, L.M., Seeger, C.M., Day, W.C., and Sidder, G.B., 1991, Rare earth element- and gold-bearing breccia pipes of the Pea Ridge iron ore mine, Washington County, Missouri: Society for Mining, Metallurgy, and Exploration, Inc., Preprint no. 91–109, 14 p.

Seeger, C.M., 1992, Three-dimensional modeling of rare earth element-bearing breccia pipes at the Pea Ridge mine, southeast Missouri—What can it tell us?: Geological Society of America Abstracts with Programs, v. 24, no. 4, p. 63–64.

Seeger, C.M., Nuelle, L.M., Marikos, M.A., 1989, Massive silicification and late stage quartz veining in the Pea Ridge Fe-REE deposit, southeast Missouri: Geological Society of America Abstracts with Programs, v. 21, no. 6, p. A34.

Sidder, G.B., Day, W.C., Nuelle, L.M., Seeger, C.M., and Kisvarsanyi, E.B., 1993a, Mineralogic and fluid inclusion studies of the Pea Ridge iron–rare-earth-element deposit, southeast Missouri, *in* Scott, R.W., Jr., Detra, P.S., and Berger, B.R., eds., Advances related to United States and International mineral resources—Developing frameworks and exploration technologies: U.S. Geological Survey Bulletin 2039, Chapter U, p. 205–216.

Sidder, G.B., Day, W.C., and Rye, R.O., 1993b, Fluid inclusion and stable isotope data for the Pea Ridge Fe-REE orebody, Missouri: Geological Society of America Abstracts with Programs, v. 25, no. 3, p. 81.

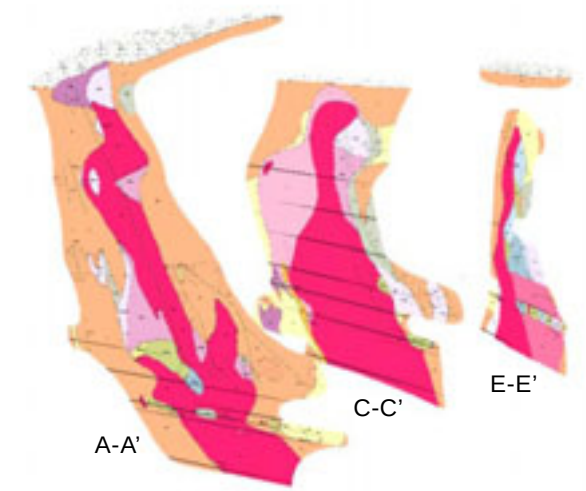
Sidder, G.B., Nuelle, L.M., Day, W.C., Rye, R.O., Seeger, C.M., and Kisvarsanyi, E.B., 1991, Paragenesis and conditions of formation of the Pea Ridge iron and rare-earth-element deposit, Missouri: Geological Society of America Abstracts with Programs, v. 23, no. 5, p. A292.

Sims, P.K., Kisvarsanyi, E.B., and Morey, G.B., 1987, Geology and metallogeny of Archean and Proterozoic basement terranes in the northern Midcontinent, U.S.A.—An overview: U.S. Geological Survey Bulletin 1815, 51 p.

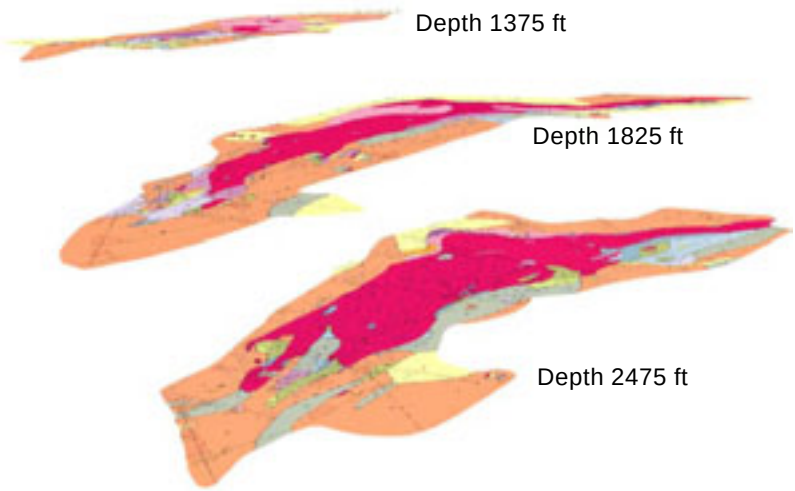
3D Subsurface Model Using Manifolds

Manifolds can be used in TNT 3D perspective views to depict cross-sections with any orientation. You can also use multiple manifold sections with different locations and orientations in a single view to reveal the 3D geometry of objects, such as geologic units in the subsurface. The subsurface model on this page shows the shape of the ore body and enclosing rock units at a subsurface iron mine in Missouri, USA. The mine workings include vertical shafts connecting networks of horizontal tunnels at various depths below the surface. The model incorporates geologic maps (horizontal sections) of selected depth levels and interpreted vertical cross-sections, each of which has been georeferenced with 3D control points to create a planar manifold surface. The perspective view with both horizontal and vertical sections can be viewed from any orientation to help visualize the 3-dimensional shape of the ore body and other rock units.

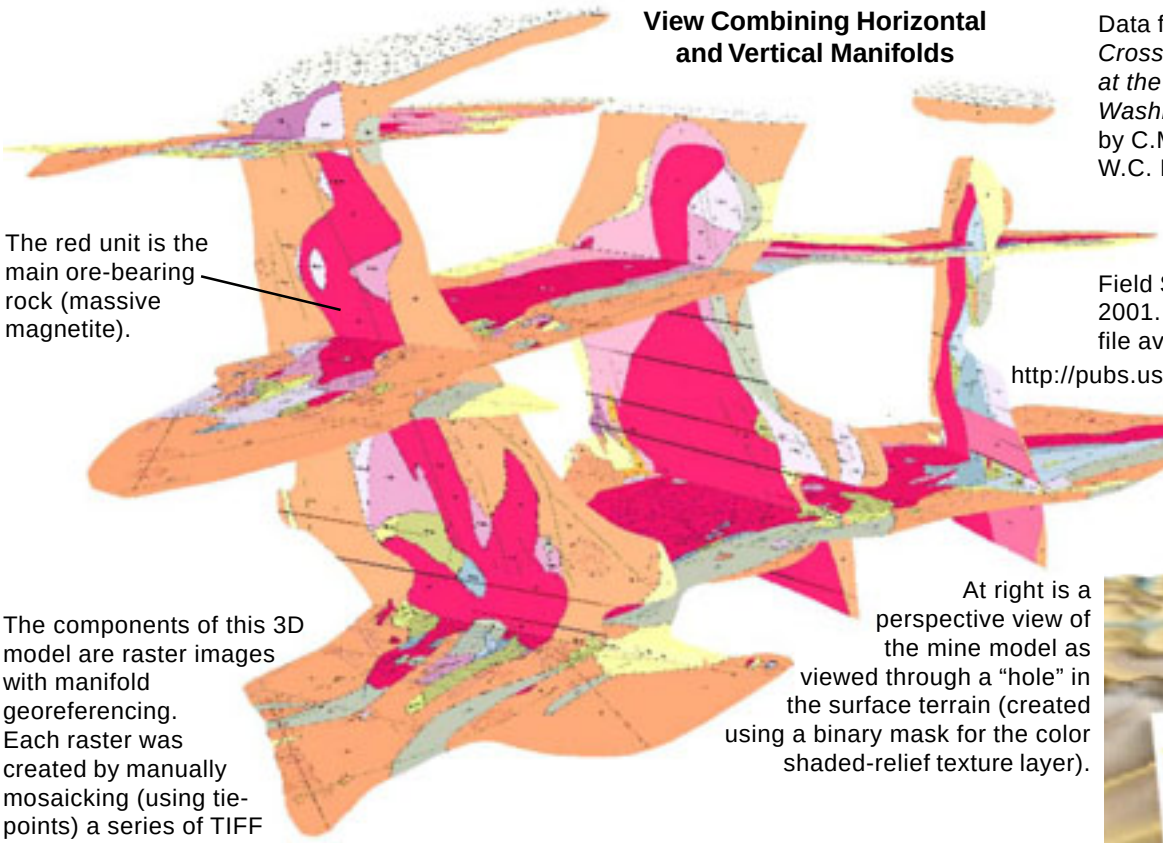
Perspective View of Vertical Section Manifolds



Perspective View of Horizontal Section Manifolds



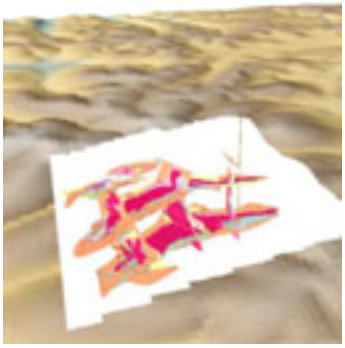
View Combining Horizontal and Vertical Manifolds



Data from: *Geologic Maps and Cross-Sections of Mine Levels at the Pea Ridge Iron Mine, Washington County, Missouri*, by C.M. Seeger, L.M. Nuelle, W.C. Day, G.B. Sidder, M.A. Marikos, and D.C. Smith; U.S. Geological Survey Miscellaneous Field Studies Map MF-2353, 2001. Adobe Acrobat (PDF) file available online at: http://pubs.usgs.gov/mf/2001/mf-2353/

The components of this 3D model are raster images with manifold georeferencing. Each raster was created by manually mosaicking (using tie-points) a series of TIFF files screen-captured from displays of the large-format pages in the source PDF file. Vector versions of the maps and sections (if available) would produce a better-quality display.

At right is a perspective view of the mine model as viewed through a "hole" in the surface terrain (created using a binary mask for the color shaded-relief texture layer).



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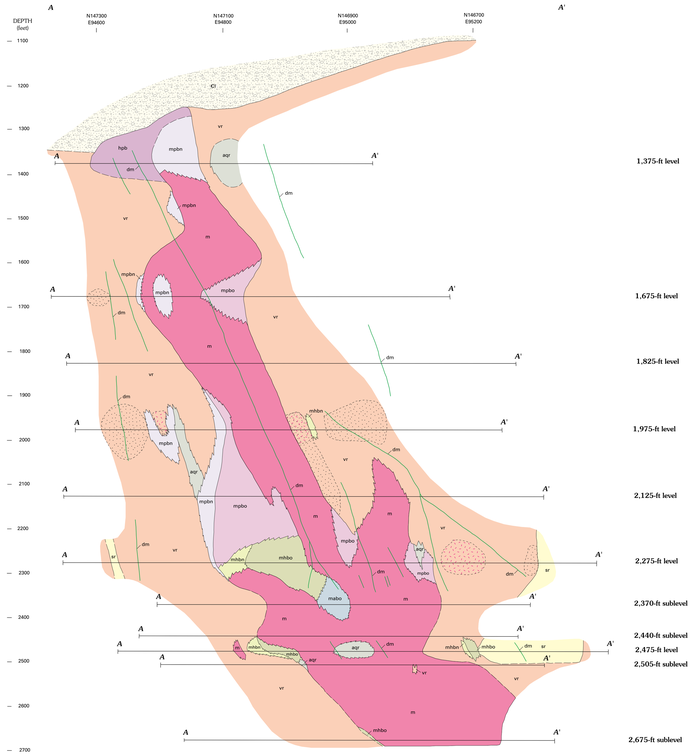
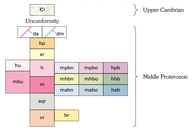


CORRELATION OF MAP UNITS



LIST OF MAP UNITS

- Cl — **Lamotte Sandstone (Upper Cambrian)**

MIDDLE PROTEROZOIC UNITS

- da — **Aplite dikes**
- dm — **Mafic dikes**
- bp — **REE mineral-bearing breccia pipes**
- sr — **Silicified rock**
- h — **Specular hematite**
- hu — **Hematite, undivided**
- m — **Magnetite**
- **Pseudobreccia**
  - mpbn — **Magnetite-cemented pseudobreccia non-ore**
  - mpbo — **Magnetite-cemented pseudobreccia ore**
  - hpb — **Hematite-cemented pseudobreccia**
- **Iron oxide-cemented heterolithic breccia**
  - mhbn — **Magnetite-cemented heterolithic breccia non-ore**
  - mhbo — **Magnetite-cemented heterolithic breccia ore**
  - hbb — **Hematite-cemented heterolithic breccia**
- **Iron oxide-cemented amphibole breccia**
  - mabn — **Magnetite-cemented amphibole breccia non-ore**
  - mabo — **Magnetite-cemented amphibole breccia ore**
  - hab — **Hematite-cemented amphibole breccia**
- mbu — **Magnetite-cemented breccia, undivided**
- aqr — **Amphibole-quartz rock**
- vr — **Volcanic rocks**
- br — **Banded rock**

Contact—Dashed where projected or inferred; jagged where extremely gradational

Fault—Showing approximate dip where known. Dashed where projected or inferred. *R*, reverse fault

Mine workings—Open-ended workings indicate stopes or abandoned areas

Development drill holes

- **Flat**
- **Inclined up**
- **Inclined down**
- **Vertical**—Cross sections only

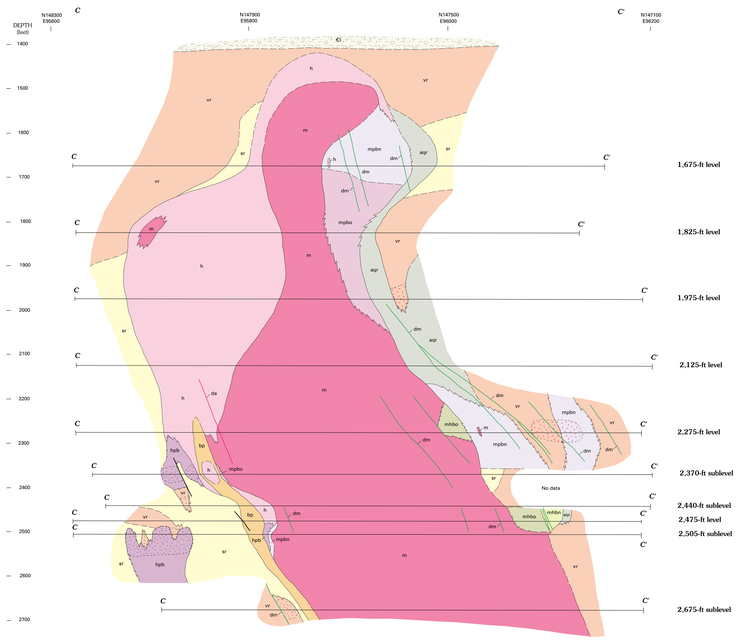
Shaft location

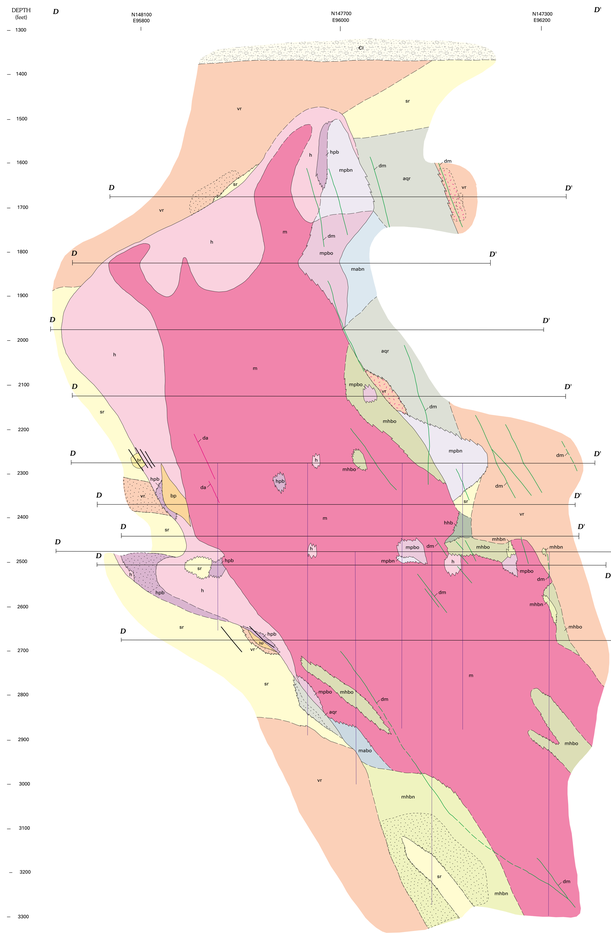
Altered rock

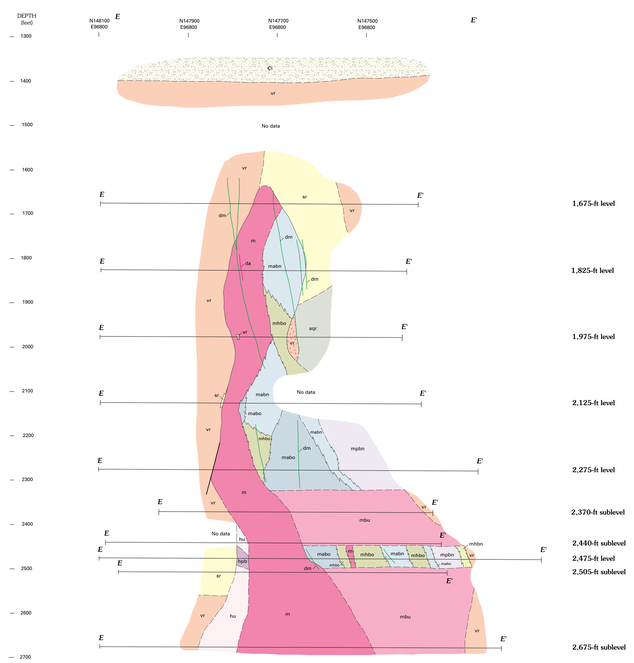
- **Silicification and potassium feldspar alteration**
- **Amphibole alteration**

SCALE 1:2,400

200 100 0 200 400 FEET
60C 30C 30C 60C 120C







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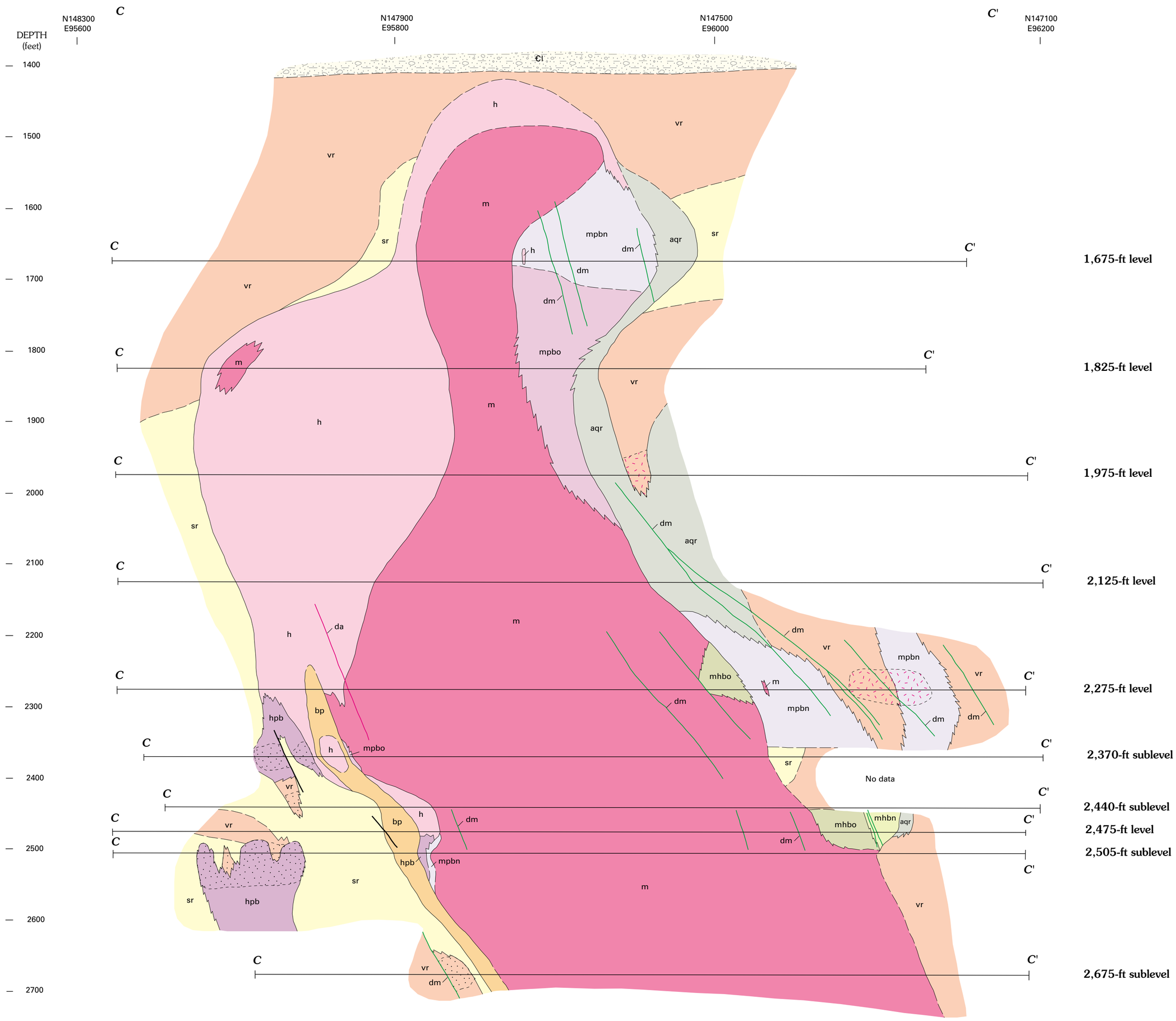

GEOLOGIC MAPS AND CROSS SECTIONS OF MINE LEVELS AT THE PEA RIDGE IRON MINE, WASHINGTON COUNTY, MISSOURI

By

C.M. Seeger,[1] L.M. Nuelle,[2] W.C. Day,[3] G.B. Sidder,[4] M.A. Marikos,[5] and D.C. Smith[1]

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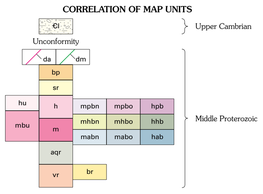
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES MAP MF–2353
Version 1.0
SHEET 1 OF 5
Pamphlet accompanies map

CORRELATION OF MAP UNITS



LIST OF MAP UNITS

- **Cl** — **Lamotte Sandstone (Upper Cambrian)**
- **MIDDLE PROTEROZOIC UNITS**
- **da** — **Aplite dikes**
- **dm** — **Mafic dikes**
- **bp** — **REE mineral-bearing breccia pipes**
- **sr** — **Silicified rock**
- **h** — **Specular hematite**
- **hu** — **Hematite, undivided**
- **m** — **Magnetite**
- **Pseudobreccia**
  - **mpbn** — **Magnetite-cemented pseudobreccia non-ore**
  - **mpbo** — **Magnetite-cemented pseudobreccia ore**
  - **hpb** — **Hematite-cemented pseudobreccia**
- **Iron oxide-cemented heterolithic breccia**
  - **mhbn** — **Magnetite-cemented heterolithic breccia non-ore**
  - **mhbo** — **Magnetite-cemented heterolithic breccia ore**
  - **hhb** — **Hematite-cemented heterolithic breccia**
- **Iron oxide-cemented amphibole breccia**
  - **mabn** — **Magnetite-cemented amphibole breccia non-ore**
  - **mabo** — **Magnetite-cemented amphibole breccia ore**
  - **hab** — **Hematite-cemented amphibole breccia**
- **mbu** — **Magnetite-cemented breccia, undivided**
- **aqr** — **Amphibole-quartz rock**
- **vr** — **Volcanic rocks**
- **br** — **Banded rock**

Contact—Dashed where projected or inferred; jagged where extremely gradational

Fault—Showing approximate dip where known. Dashed where projected or inferred. *R*, reverse fault

Mine workings—Open-ended workings indicate stopes or abandoned areas

Development drill holes

- **Flat**
- **Inclined up**
- **Inclined down**
- **Vertical**—Cross sections only

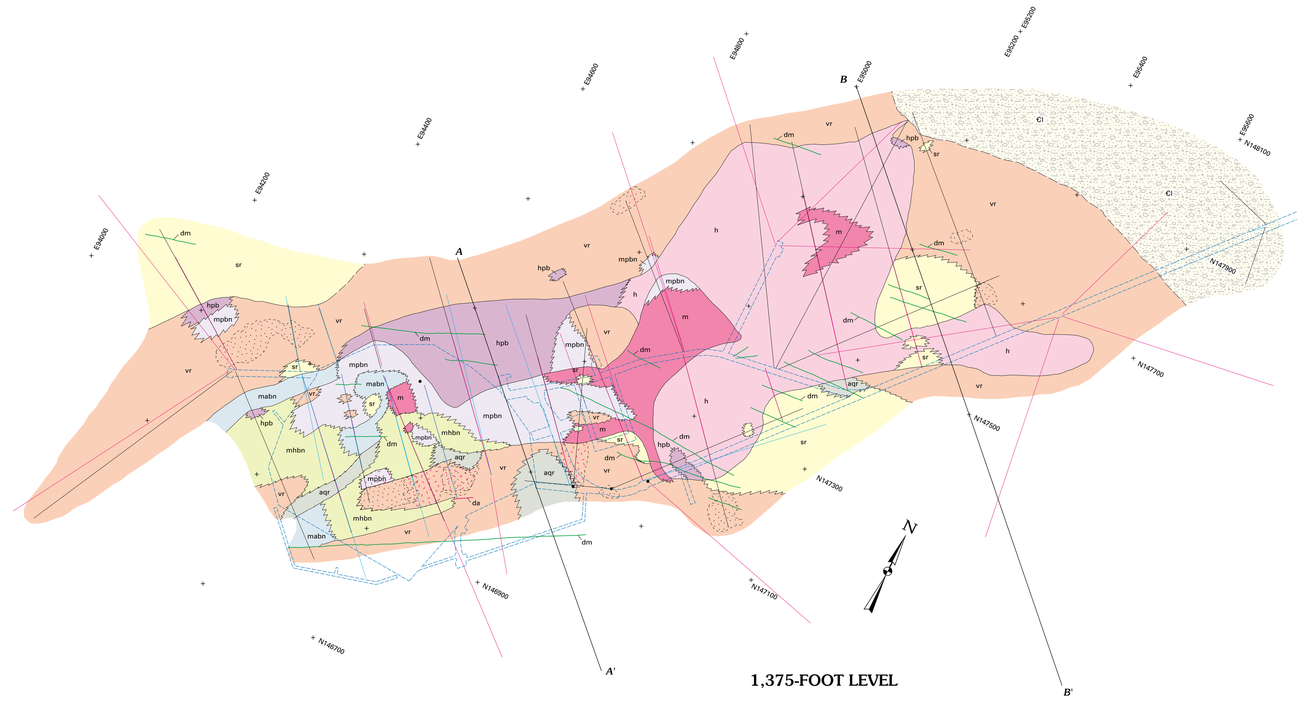
Shaft location

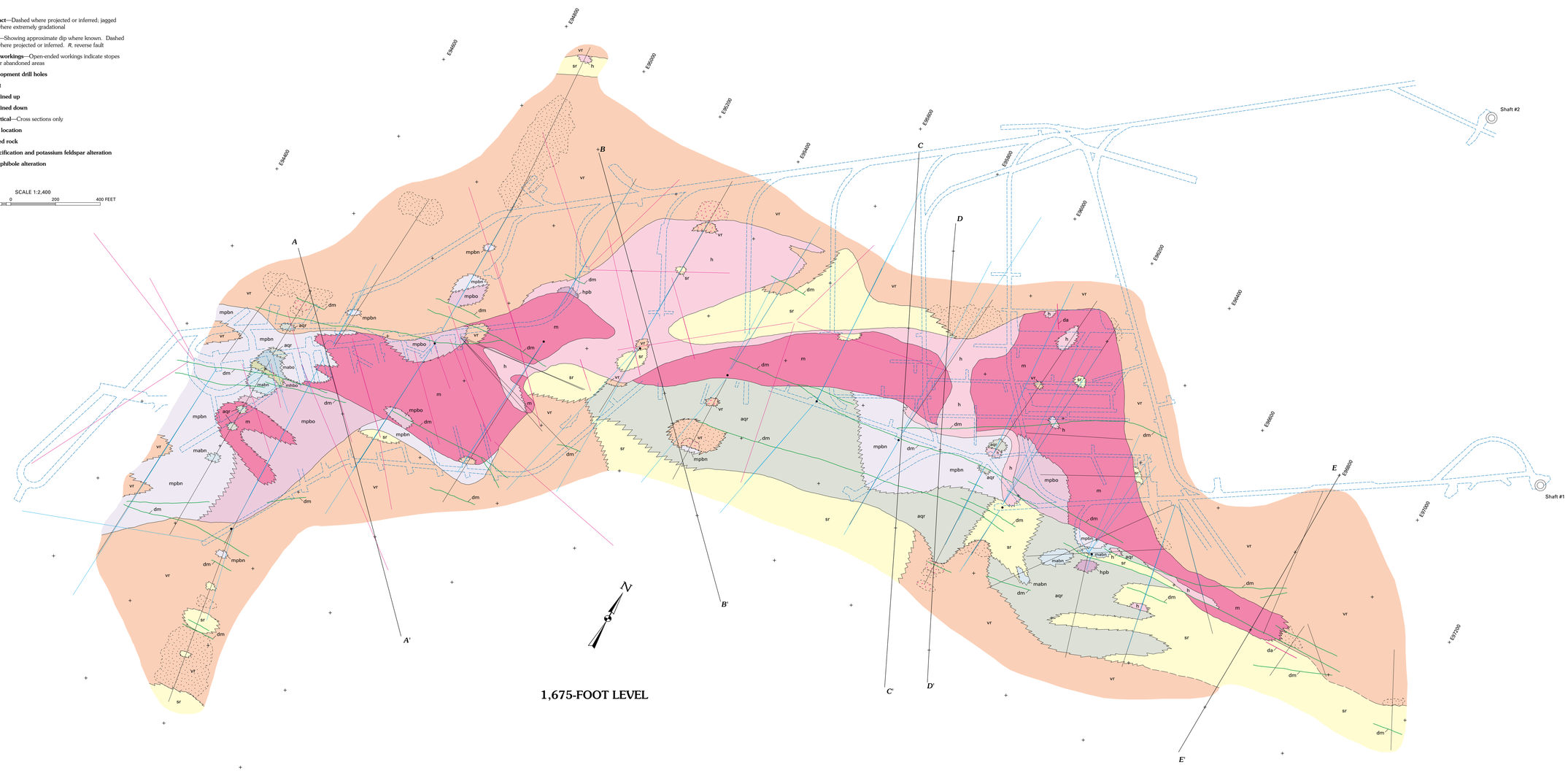
Altered rock

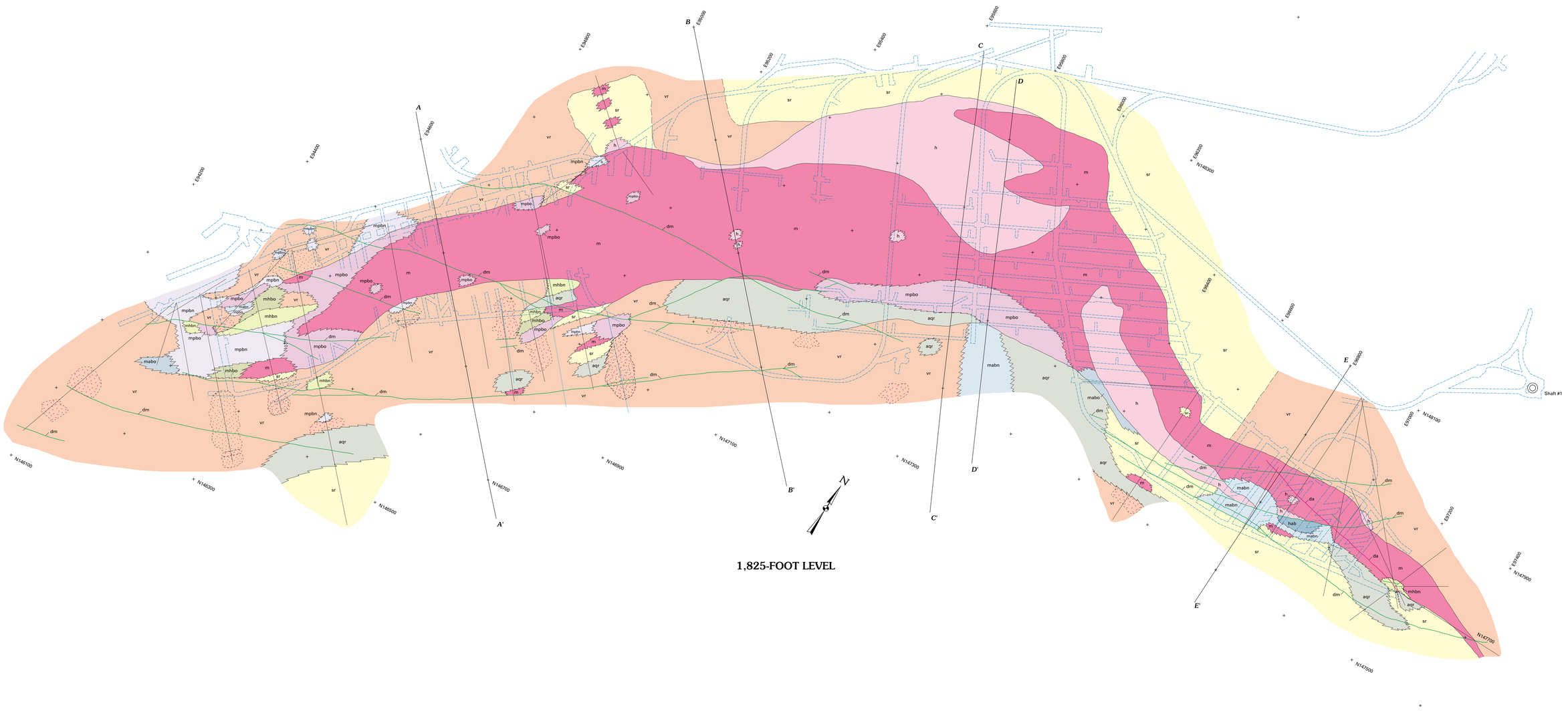
- **Silicification and potassium feldspar alteration**
- **Amphibole alteration**

SCALE 1:2,400

200 100 0 200 400 FEET







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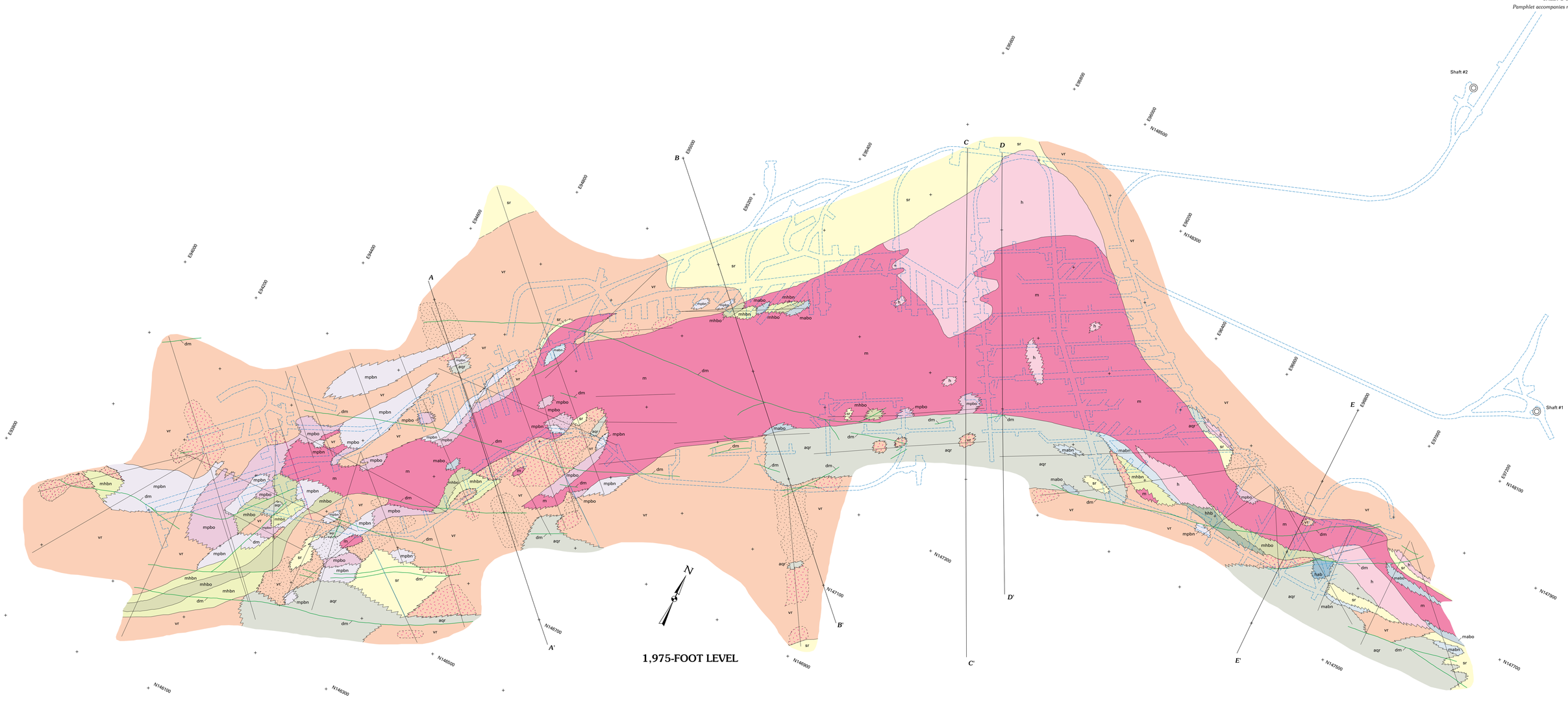
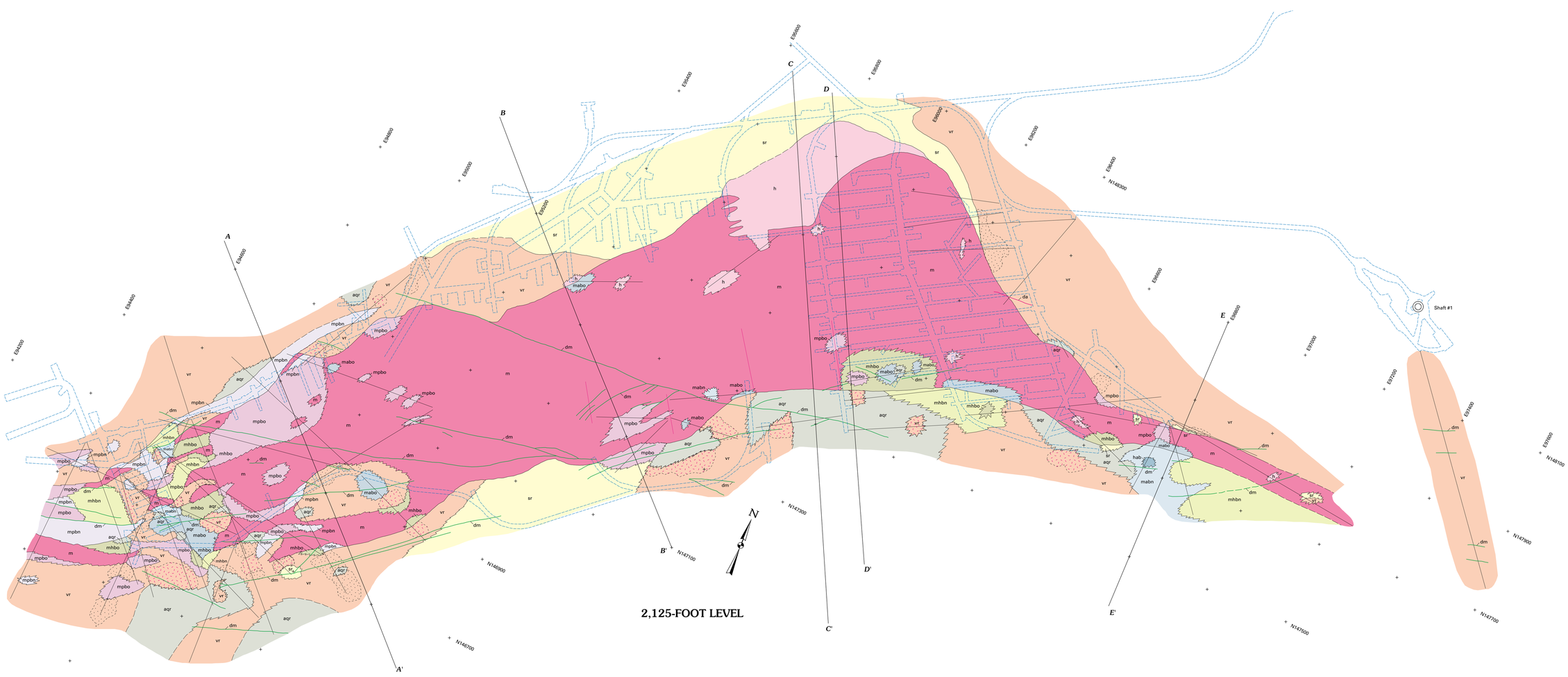
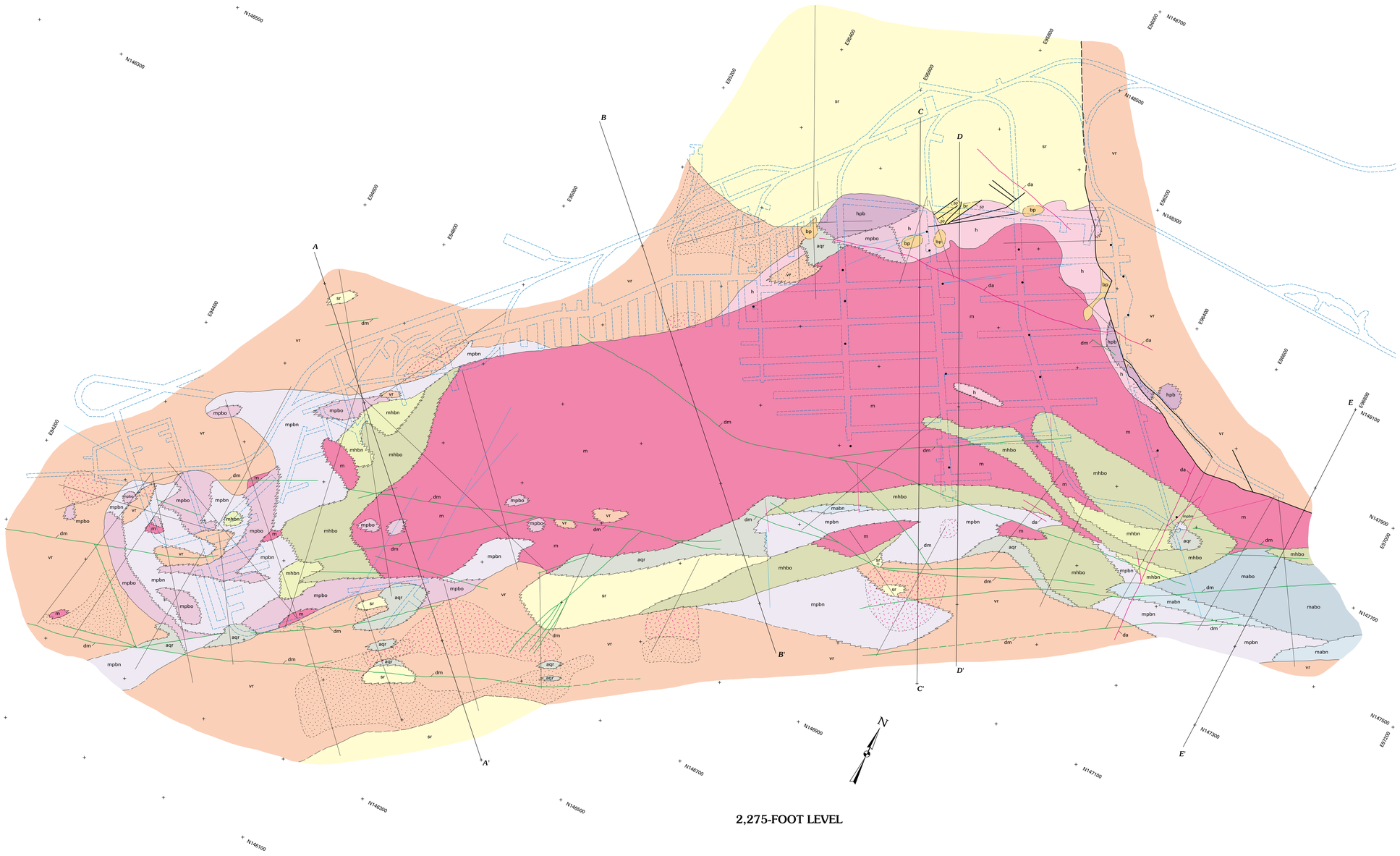
MISCELLANEOUS FIELD STUDIES MAP MF–2353
Version 1.0
SHEET 2 OF 5
Pamphlet accompanies map



1,975-FOOT LEVEL

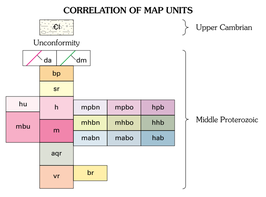


2,125-FOOT LEVEL



2,275-FOOT LEVEL

CORRELATION OF MAP UNITS



LIST OF MAP UNITS

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- sr — Silicified rock
- h — Specular hematite
- hu — Hematite, undivided
- m — Magnetite

Pseudobreccia

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- mpbo — Magnetite-cemented pseudobreccia ore
- hpb — Hematite-cemented pseudobreccia

Iron oxide-cemented heterolithic breccia

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200 100 0 200 400 FEET

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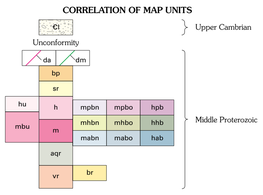
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES MAP MF–2353
Version 1.0
SHEET 3 OF 5
Pamphlet accompanies map

CORRELATION OF MAP UNITS



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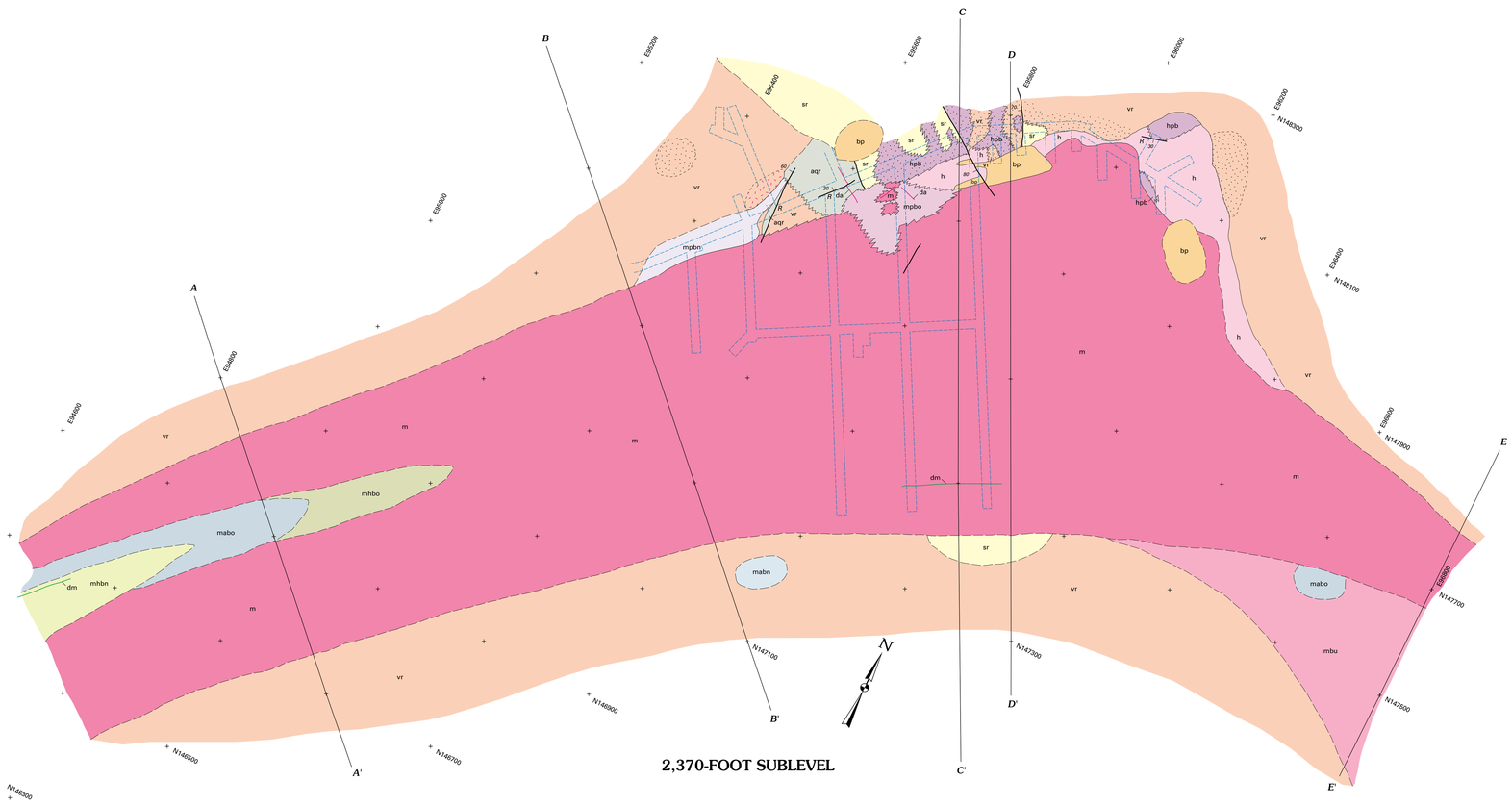
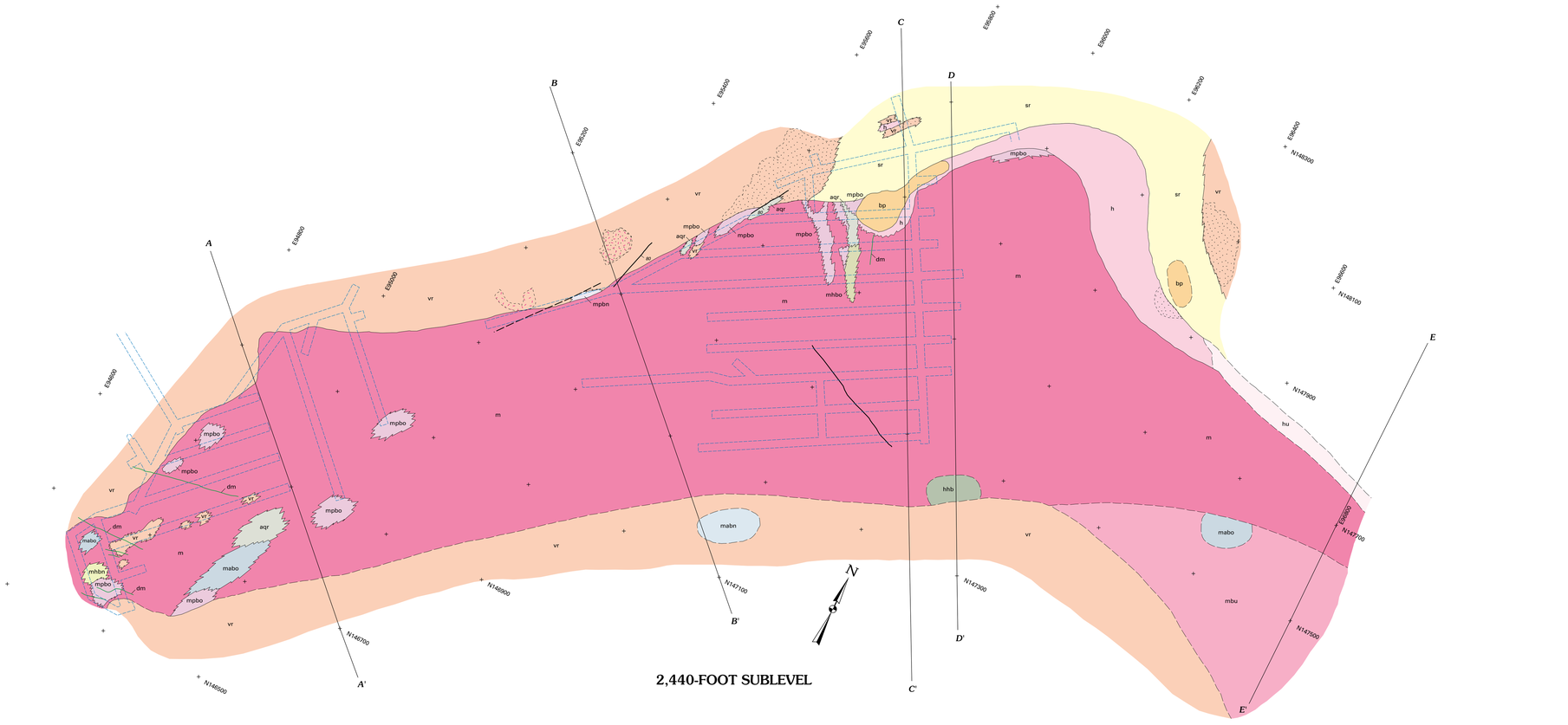
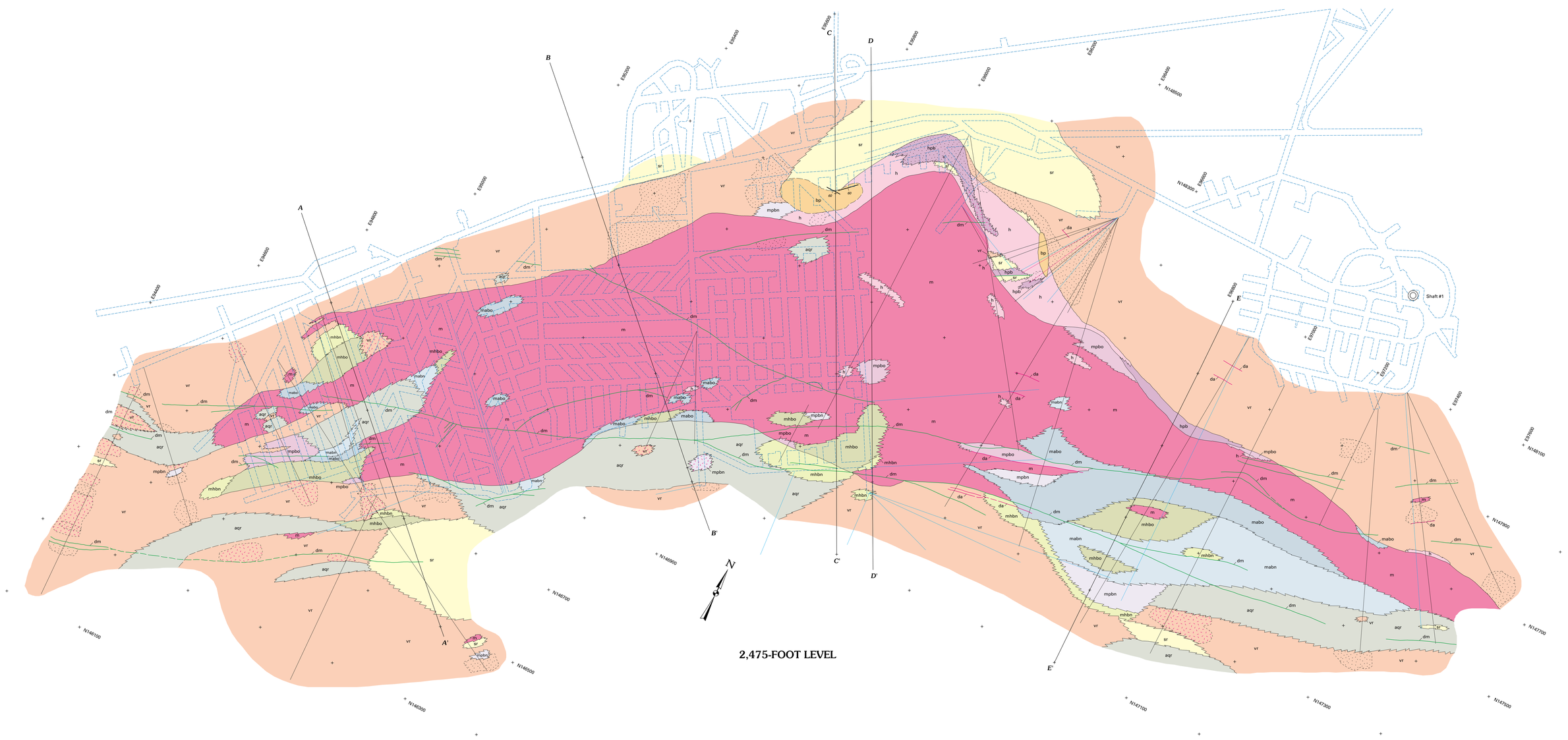
SCALE 1:2,400
200 100 0 200 400 FEET







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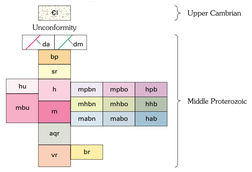

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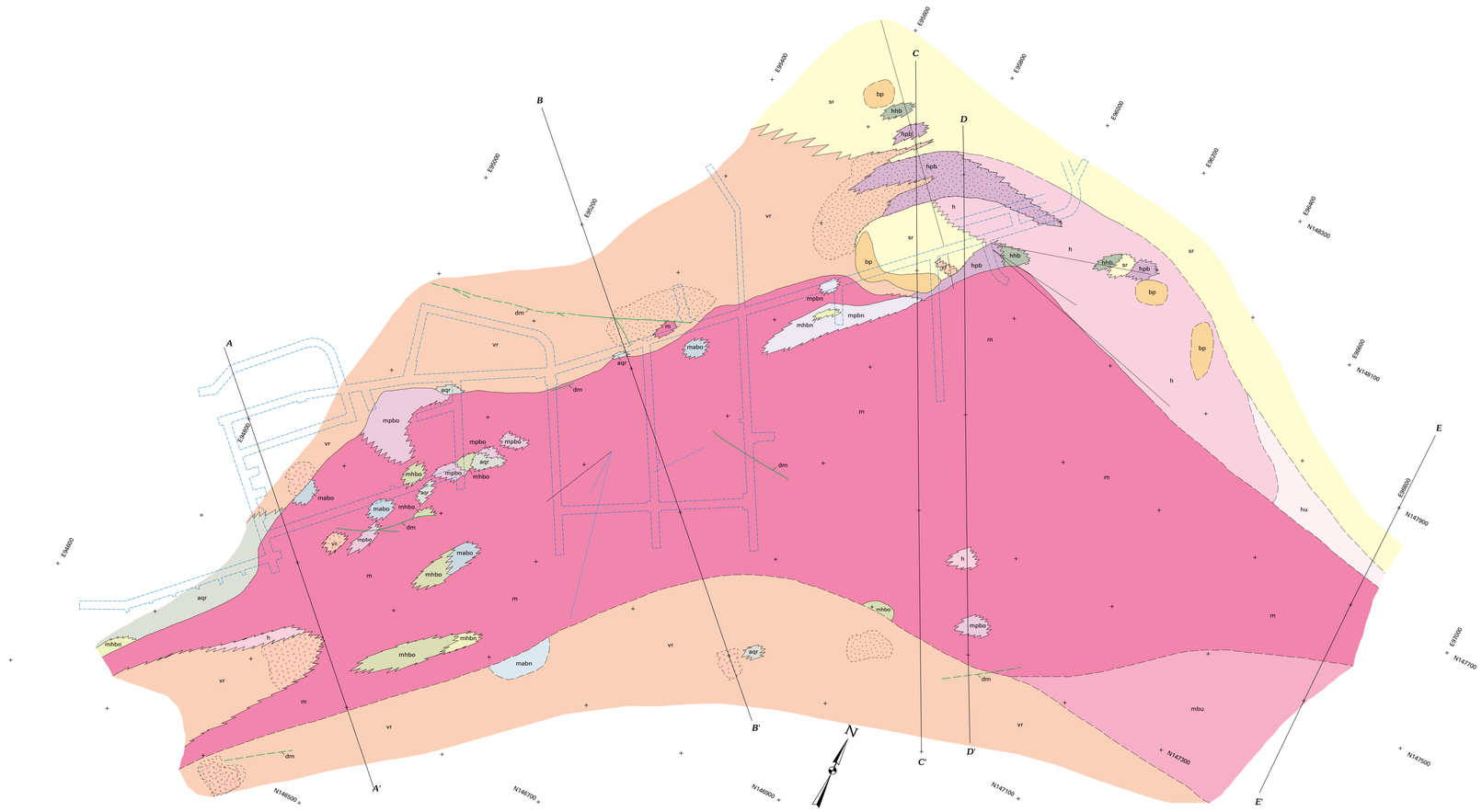
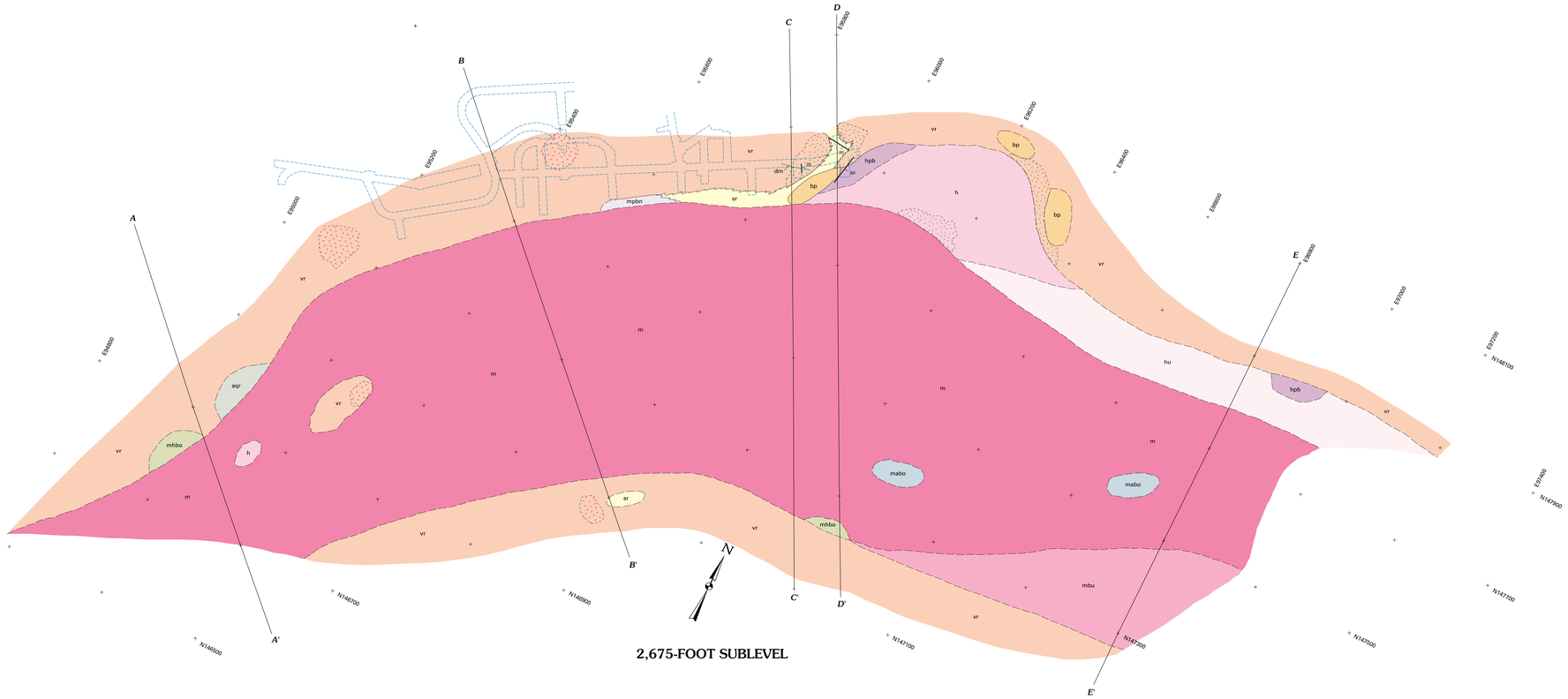


2,505-FOOT SUBLEVEL



2,675-FOOT SUBLEVEL

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