CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

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James Doyle Sell Mining Collection

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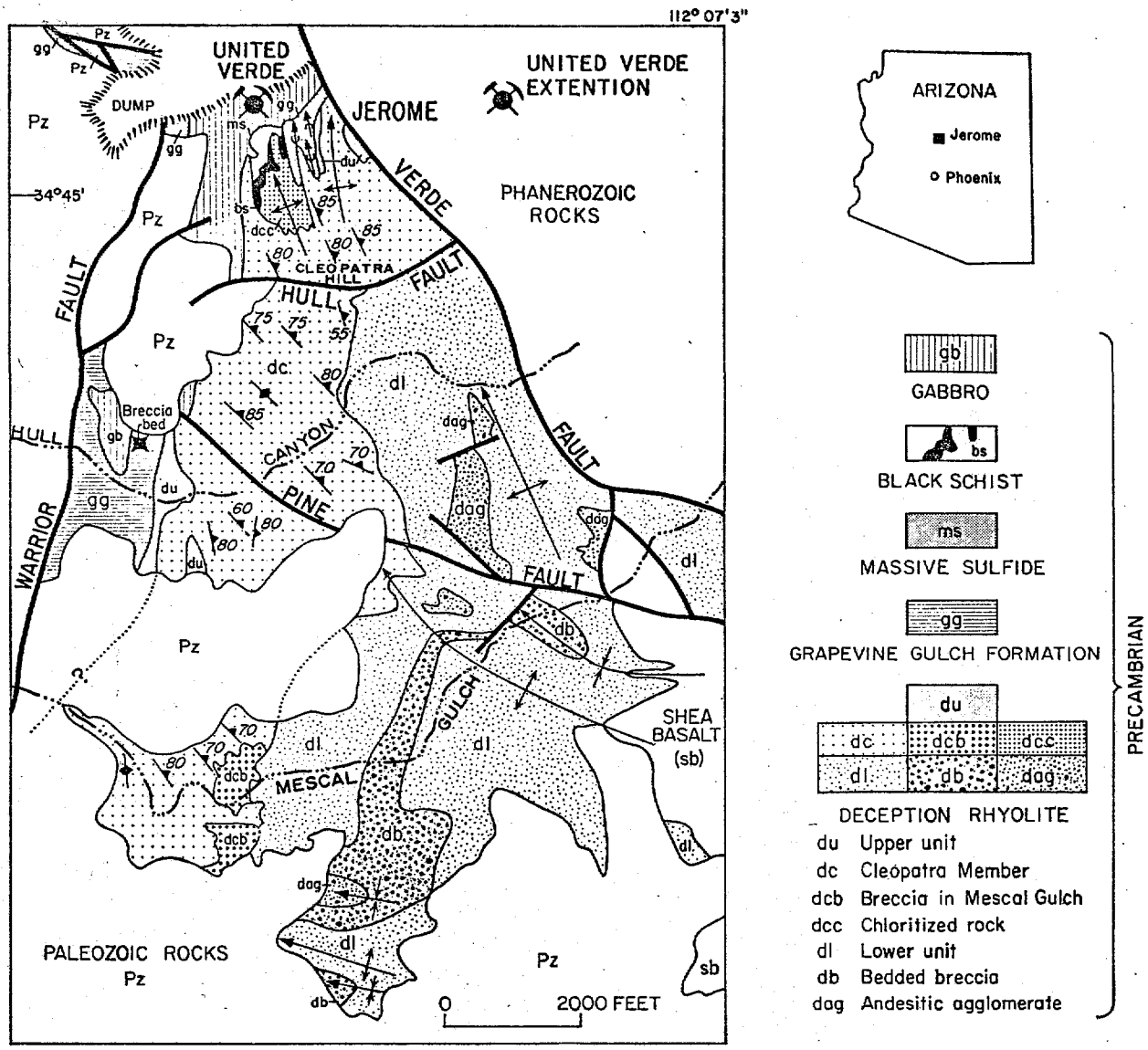

FIG. 1. Geologic map of area south of Jerome modified from Anderson and Creasey (1958, Pl. 1); inset shows location of Jerome.

years Anderson has been reviewing the field evidence at Jerome to determine whether this interpretation can be applied. Nash found fluid inclusions in thin sections of some of the host rocks at the United Verde deposit, and in March 1971 he collected extensively at Jerome for fluid inclusion studies and joined Anderson in a review of the geology.

This paper presents evidence that the massive sulfide deposits at Jerome may have formed during and following the accumulation of flow-banded rocks, breccias, and crystal tuffs containing crystals of quartz ("quartz porphyry"). The review leading to this interpretation was stimulated by the presence of clasts of quartz porphyry and chloritized quartz porphyry in a small lens of volcanic breccia in the Grapevine Gulch Formation (X on Fig. 1, shown to C. A. Anderson by J. S. Phillips, 1965), suggesting that some quartz porphyry was emplaced before the accumulation of the Grapevine Gulch rocks. Earlier interpretations will not be reviewed, as they have been extensively presented in detail in another paper (Anderson and Creasey, 1958).

General Geology

The massive sulfide deposits occur in the upper part of the Precambrian Ash Creek Group, which regionally consists of nonfoliated basalts, rhyolitic tuffs, breccias, and flows, dacitic flows and domes,

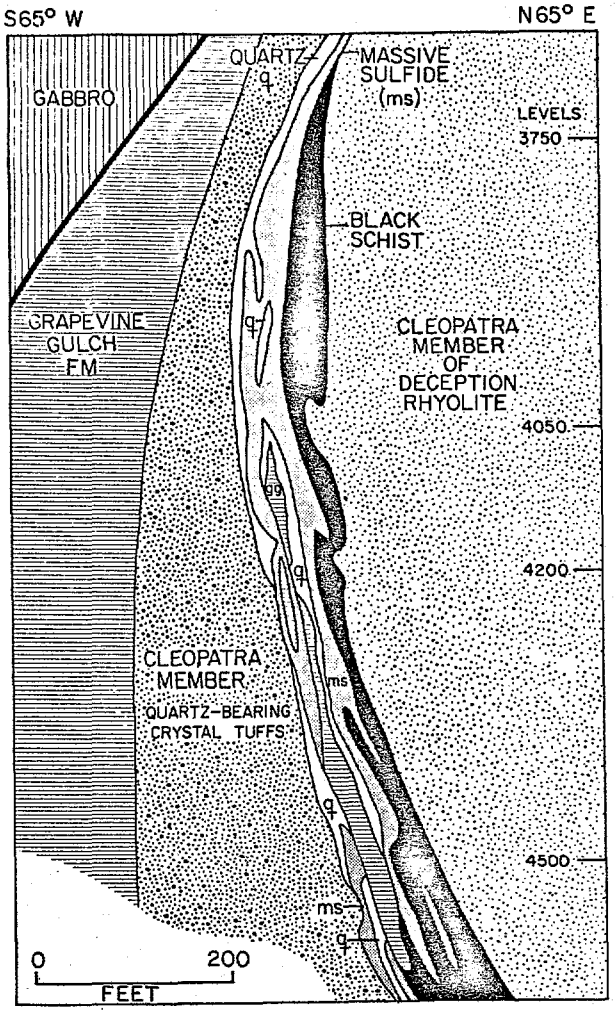

FIG. 4. Vertical section through the North ore body of the United Verde mine, showing intertonguing of quartz-bearing crystal tuffs of the Cleopatra Member with the fine-grained bedded rocks of the Grapevine Gulch Formation. Modified from Anderson and Creasey (1958, Pl. 7).

intrusive into, or intercalated with, the Cleopatra Member.

East of the United Verde mine (Fig. 1 du), poorly exposed light-gray to white rocks are assigned to the upper unit. On the 500 and 1,000 levels of the mine, rhyolitic breccia, 35 to 100 feet thick, is exposed beneath the westerly mass (Fig. 1, du). This breccia, containing some rhyolitic clasts 1 to 2 feet long, is similar in appearance to the Deception breccia exposed west of the Cleopatra in Hull Canyon (Fig. 1, du).

Grapevine Gulch Formation

The lower part of the Grapevine Gulch Formation, where it is well exposed in Hull Canyon, consists of alternating beds of breccia, coarse-grained tuffaceous rocks, well-bedded fine-grained tuffaceous rocks, cherty shales, and chert beds. The contact with the underlying Deception Rhyolite is sharp, revealed by the excellent bedding in the Grapevine Gulch in contrast to the older massive Deception breccias.

In and adjacent to the United Verde mine, the fine-grained rocks of the Grapevine Gulch Formation are widely exposed, but the coarse-grained tuffs are limited to thin beds exposed on intermediate levels. In the upper levels, the fine-grained rocks of the Grapevine Gulch Formation intertongue with the massive sulfide lenses, particularly on their northern margins.

North of the Hull fault, bedded purple crystal lithic tuffs crop out in a narrow band adjacent to the gabbro. East of these purple tuffs are typical fine-grained bedded Grapevine Gulch rocks that overlie massive to foliated sericitic rock containing a minor amount of quartz that may be the upper unit of the Deception Rhyolite (the outcrops of these rocks are too narrow to show on Figure 1).

Purple quartz-bearing crystal tuffs are exposed underground in the United Verde mine between the massive sulfide lens of the main ore body and the gabbro to the west, and on the 1,000 level, northeast of the massive sulfide, purple crystal tuffs intertongue with the fine-grained bedded Grapevine Gulch Formation. On the lower levels of the mine, purple and green quartz-bearing crystal tuffs occur between fine-grained bedded Grapevine Gulch rocks and the sulfide lenses of the North ore body, which contains tongues of similar Grapevine Gulch rocks (Fig. 4).

These stratigraphic relations clearly indicate that rhyolitic volcanism characterized by conspicuous quartz crystals continued locally after deposition of well-bedded fine-grained rocks that are defined as Grapevine Gulch Formation; this is shown schematically on Figure 5. Complex intertonguing of flows, breccias, crystal tuffs, and fine-grained tuffaceous rocks is common throughout the Ash Creek Group and appears to have occurred at and near the United Verde mine. The stratigraphic units are defined by their lithology and do not necessarily reflect time units, and the purple and green quartz-bearing tuffs that intertongue with the Grapevine Gulch fine-grained bedded rocks are assigned to the Cleopatra Member (Fig. 5).

Massive Sulfide Deposits

United Verde mine

The main and North ore bodies in the United Verde mine provide most of the data pertinent to the timing and mode of formation of the massive sulfide lenses and the related "black schist" and "quartz porphyry" ores. Black schist is the term

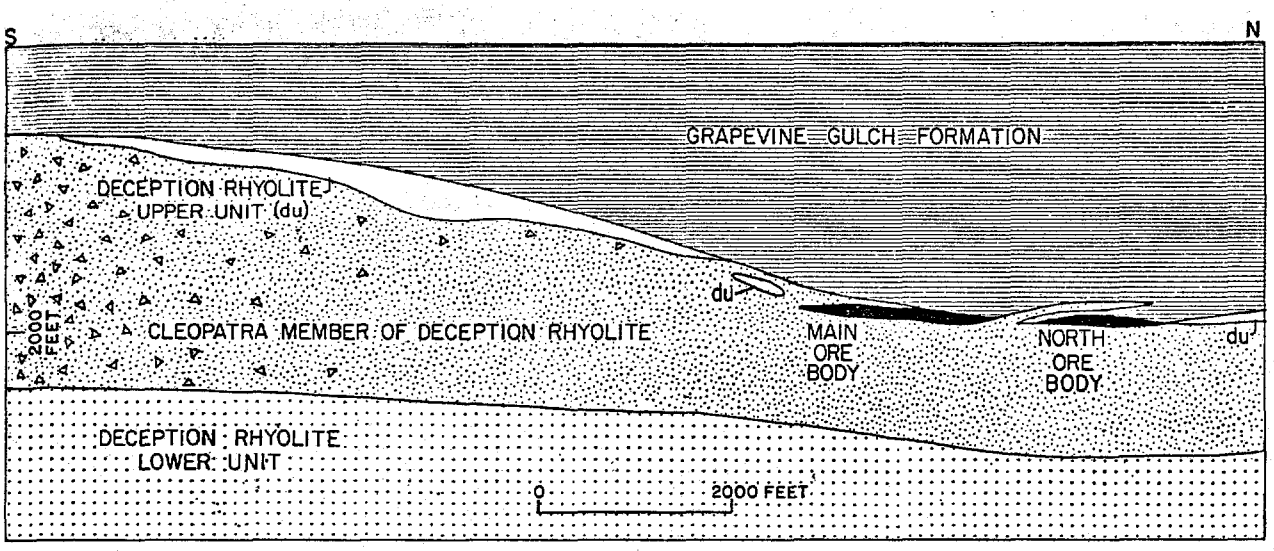

FIG. 5. Interpretative section of the Cleopatra Member and associated rocks after accumulation and before folding. In the northern part of the section, the Cleopatra Member is appreciably thinner and finer grained than to the south. The youngest crystal tuffs in the Cleopatra Member intertongue with the massive sulfide lenses, upper unit of the Deception Rhyolite, and lower beds of the Grapevine Gulch Formation.

used for the chlorite-rich rock that locally contains sufficient chalcopyrite to form ore, and "quartz porphyry" ore consists of intersecting veinlets of chalcopyrite in the Cleopatra Member of the Deception Rhyolite; these two types of ore are distinctly younger than the ore in massive sulfide lenses and will be discussed separately.

The massive sulfide lens making up the major part of the main ore body is pipelike with the bearing of the axis about N20°W and plunging 50° to 65°N (Fig. 6). The horizontal area of this lens on the upper levels ranges from 220,000 to 260,000 square feet; it increases below the 900 level to 500,000 square feet on the 1,500 level and diminishes on lower levels to 60,000 square feet on the 3,300 level. The contact of the massive sulfide with adjacent rocks is generally sharp, but in places it is gradational into disseminated pyritic rock.

In the upper levels of the mine, lenses of white quartz, commonly cut by veinlets of pyrite and chalcopyrite, are present on the hanging wall side of the massive sulfide; in places the quartz is overlain by the Grapevine Gulch Formation. On the 1,650 level, some quartz lenses are within the massive sulfide (Anderson and Creasey, 1958, pl. 7). From the 2,250 level to the 3,300 level, quartz is present largely on the west side of the massive sulfide lens.

One of the main objectives of this paper is to present the view that the massive pyritic lenses are essentially syngenetic and later deformed. The contacts between the massive sulfide and tuffaceous rocks of the Grapevine Gulch Formation, best exposed on the hanging-wall side of the pipe on the upper levels,

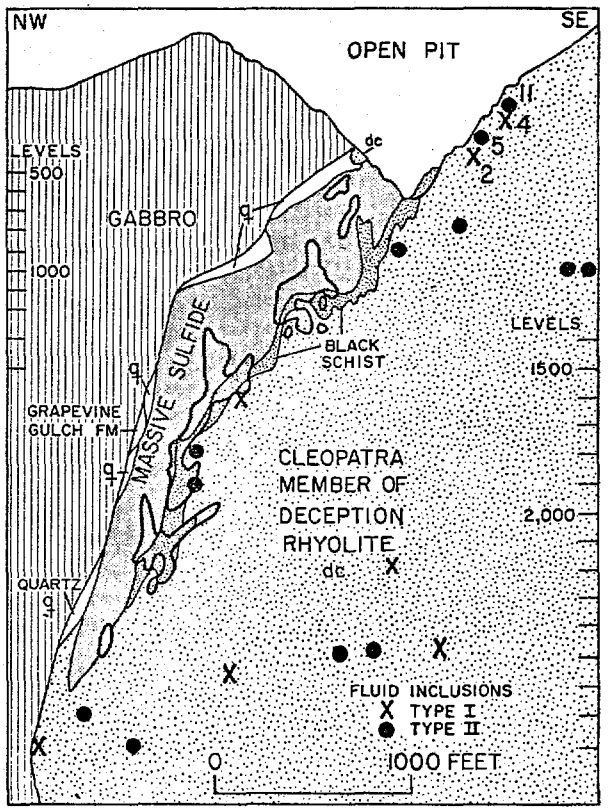

FIG. 6. Vertical section through main ore body of the United Verde mine. Heavy black lines indicate the margins of stopes intersected by the plane of the section. Fluid inclusions containing liquid CO_2 (type II) are restricted to rocks older than the gabbro and near the massive sulfide. Numbers next to locations in open pit refer to multiple samples projected into the plane of the section. Section from Anderson and Creasey (1958, p. 112).

stratigraphically above the rhyolite. This evidence indicates that iron-magnesium metasomatism of Cleopatra rocks occurred during the accumulation of the Cleopatra Member; presumably this was hydrothermal alteration possibly related to hot dense brines. Some of the small masses of black schist in Mescal Gulch may have formed at that time, as the source of the iron and magnesia could be pillow basalts lower in the section of the Ash Creek Group.

Adjacent to the massive sulfide lenses (Figs. 4, 6, 8), intense iron-magnesium metasomatism produced black schist that is a fine-grained aggregate of chlorite forming a net of interlocking flakes or having a preferred orientation. The rock is massive, splintery, or foliated. Some of the chlorite replaces sericite along foliation planes or veinlets and partly replaced quartz crystals appear at the margins of the black schist in contact with the Cleopatra. The chlorite forming the black schist has refractive indices ranging from 1.585 to 1.620, indicating Fe/Fe + Mg ratios of 10 to 40 percent (Albee, 1962, p. 865).

In the main ore body, much of the black schist is on the footwall (south), stratigraphically older side of the massive sulfide (Fig. 6), but from the 1,000 level to below the 3,300 level, appreciable black schist occurs on the east side (stratigraphically younger), replacing Grapevine Gulch and Cleopatra rocks in the upper levels and Cleopatra crystal tuffs below the 2,250 level (Anderson and Creasey, 1958, pl. 7). From the 1,800 level downward, the plan outline of the massive sulfide lens is crescent shaped, and the eastern sulfide limb dips steeply to the east with black schist occurring on both the east and west sides (Anderson and Creasey, 1958, p. 116). The dip is parallel to a zone of strong foliation (Anderson and Creasey, 1958, p. 113). Three interpretations for the formation of this black schist are (1) the schist formed above and below the eastern massive sulfide limb early in the history of the deposit and before folding; (2) it may be one layer duplicated by folding; (3) it formed in this zone during and after metamorphism. We have no evidence that would favor any one of these possibilities.

The age relations of the black schist and massive sulfide lenses, deformation, and metamorphism have been controversial for decades (Anderson and Creasey, 1958, p. 121), and we are unable to resolve the problem except to indicate that it is complex. Chlorite is limited to the outer several feet of the sulfide lenses where they are in contact with the black schist, but no black schist has been found in the centers of any of the lenses. The clasts of black schist in the Cleopatra crystal tuffs in Mescal Gulch and Grapevine Gulch breccia bed clearly demonstrate black schist formation early in the depositional history. The chlorite in these clasts has Fe/Fe + Mg ratios of 38 to 55 percent, indicating a higher iron content than in most of the black schist associated with the ore deposits.

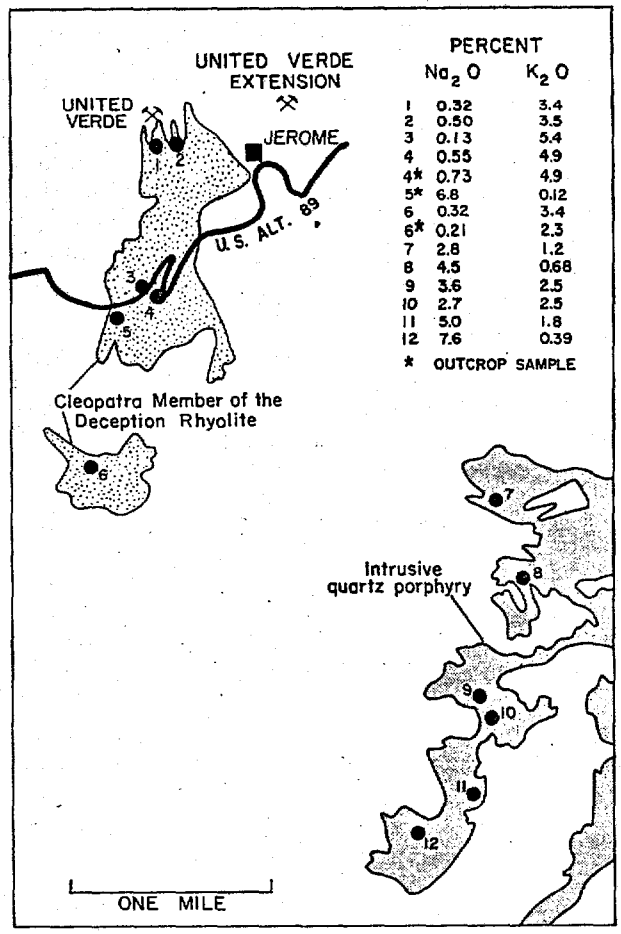

FIG. 9. Outcrops in the Jerome area of the Cleopatra Member of the Deception Rhyolite and intrusive quartz porphyry showing sample locations for Na_2O and K_2O content. Most samples represent a composite collected within an area of 20-foot radius in conjunction with gamma-ray spectrometer studies (Moxham et al., 1965).

Metamorphism

The Grapevine Gulch bedded rocks exposed at the United Verde mine are deformed into small folds of varying amplitude which are resolved into larger north-plunging anticlines and synclines (Fig. 1). Axial plane foliation is developed in the fine-grained bedded rocks (Fig. 2H). Folds are not easily recognized in the adjacent Cleopatra crystal tuffs because of their massive character, but many foliation planes are parallel to the axial plane foliation in the Grapevine Gulch rocks. The sericite defining foliation in the Grapevine Gulch and Cleopatra rocks may be recrystallized mica or earlier hydrothermal

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intrusive and younger than part of the folding proves correct, an alternative to the volcanogenic origin of massive sulfides at Jerome is required. An interchange of ideas, particularly regarding mining methods for massive sulfides, occurred near the turn of the century between the United Verde and Sudbury

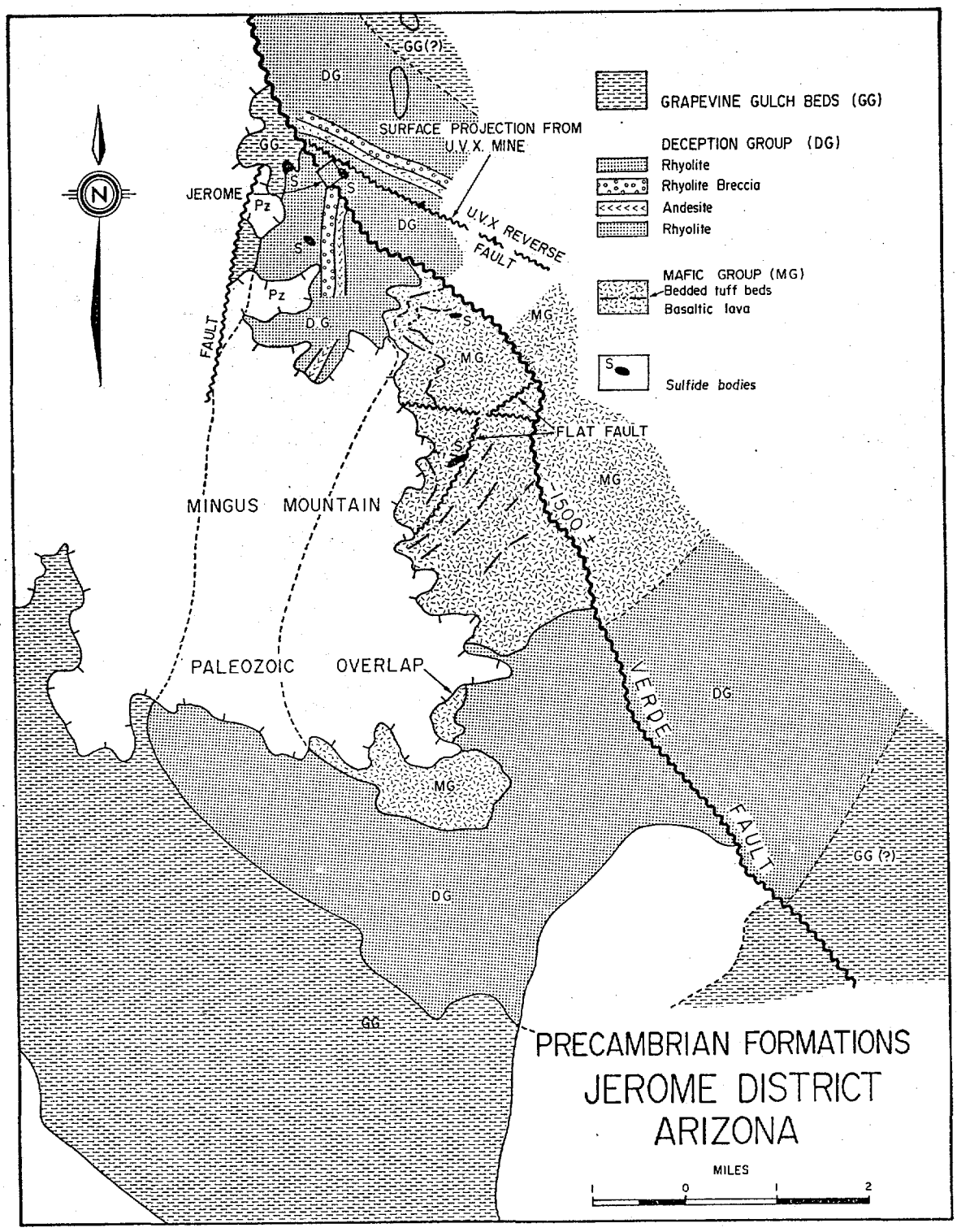


FIG. 1. Geological map, Jerome region, of major rock units forming the Precambrian Stratigraphic Sequence; south half modified after Anderson and Creasey (1958).

Hal Norman
SEG June July - '77

phase does not occur in the southern or lowest member of the series, forms a minor part of the Central or intermediate member, and a major part of the uppermost Cleopatra member, where rapid chilling and resurgence of magma appear to have occurred.

Relative Ages

Quartz porphyry, Grapevine Gulch, and older formations

If crosscutting dikes, tongues, and apophyses of quartz porphyry in Precambrian sedimentary and volcanic formations of the district provided the only evidence regarding the relative age of these rocks there would be no grounds for dispute that the porphyry was intrusive and introduced after the surficial rocks had been folded. The evidence provided by inclusions is contradictory. Along the west side of the Cleopatra mass large blocks consisting of rhyolite and tuffaceous sediments are included within and surrounded by quartz porphyry which cuts across the bedding present in the blocks and supports the evidence given by the dikes. In sharp contrast inclusions of quartz porphyry occur in the bedded rocks west of the Cleopatra Porphyry and suggest instead that the porphyry predates these rocks.

Quartz porphyry dikes cut east across folded Deception Rhyolite and underlying mafic rocks at and south of Mescal Gulch (Fig. 2; Anderson and Creasey, 1958, pl. 1). North of Mescal Gulch two tongues or apophyses from the Cleopatra mass extend east, parallel to the dikes, across the strike of the Deception group. The crosscutting relationships show that the Deception group was folded prior to the intrusion of the dikes and the tongues of Cleopatra Quartz Porphyry which were not distorted during the considerable flexing of the older volcanic rocks.

The Grapevine Gulch sedimentary beds would have been subjected to the same deformation which folded the underlying rocks before the intrusion of quartz porphyry dikes and tongues unless they were separated from the Deception Rhyolite by an unconformity. The evidence provided, in the upper part of Deception Gulch, by the strike and dip of tuff layers in the Deception group parallel to the nearby base of the Grapevine Gulch beds suggests a conformable relationship which is not negated by contrary evidence elsewhere in the district. The conformability of the sedimentary volcanic sequence in the Jerome district justifies the conclusion that the Cleopatra Quartz Porphyry is an intrusive emplaced after the Grapevine Gulch sedimentary beds had been folded. This conclusion is supported by the series of Cleopatra Quartz Porphyry tongues that extend north, in part across and in part parallel, to Grapevine Gulch beds on either side of the United Verde pit (Fig. 2).

Small inclusions of quartz porphyry, called clasts, are described in Grapevine Gulch beds on the north side of Hull Canyon (the upper part of Deception Gulch) about 4,500 feet south-southwest from the United Verde pit by Anderson and Nash (1972). Comparable inclusions of quartz porphyry occur in Grapevine Gulch beds in Haynes Gulch 3,000 feet west-northwest of the pit. The Cleopatra Quartz Porphyry outcrops 500 feet east of the Hull Canyon occurrence and 1,500 feet south of the Haynes Gulch occurrence. At Haynes Gulch quartz porphyry occurs on the north side of the Haynes sulfide deposit in the lower levels of the United Verde mine below the occurrence of inclusions in Grapevine Gulch beds at the surface and may occur also below the Hull Canyon occurrence.

In contrast, Grapevine Gulch beds form large inclusions in the Cleopatra Quartz Porphyry north of Hull Canyon between the United Verde pit and Hull Fault (Fig. 2). The inclusions, 100 feet wide and 300 to 500 feet long, contain the basal Grapevine Gulch beds and the uppermost part of the Deception Rhyolite and are completely surrounded by quartz porphyry. The Grapevine Gulch-Deception Rhyolite contacts in the inclusions have retained their original positions unchanged by the emplacement of the surrounding quartz porphyry. They form remnants of a former continuous contact that predates the crosscutting and enclosing porphyry. Another remnant of the Grapevine Gulch-Deception contact strikes north about 500 feet east of the United Verde pit and is cut off to the south by Cleopatra Quartz Porphyry together with the synclinal fold on its west side.

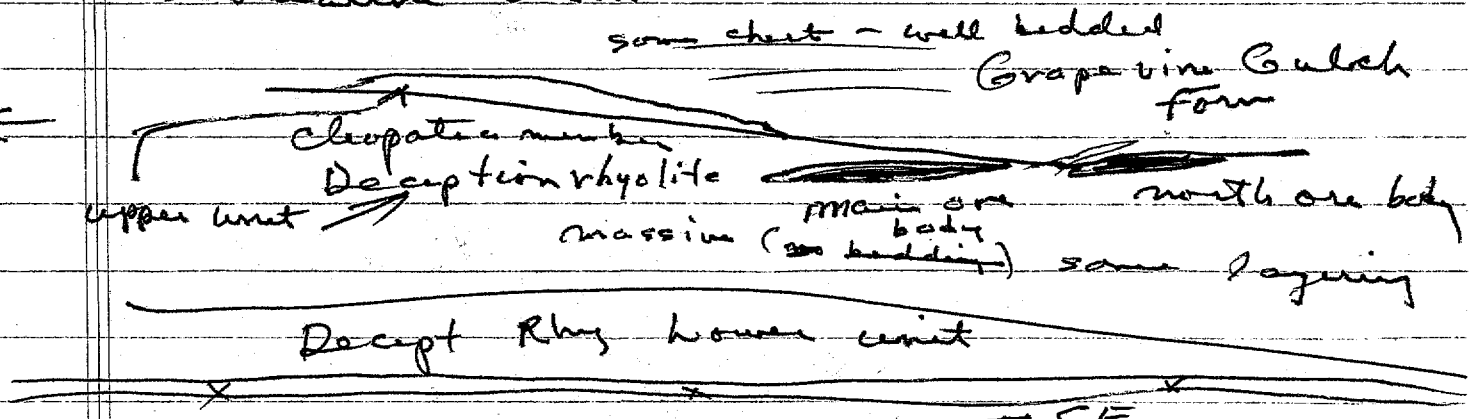
Conflicting evidence occurs also along the western boundary of the Cleopatra Quartz Porphyry south of the upper part of Deception Gulch. The uppermost part of the Deception Rhyolite at this locality is underlain by a tuff member which forms a good marker horizon. A large block of the rhyolite with the marker tuff bed on its eastern side is completely enclosed by porphyry south of the gulch (Fig. 2). In one outcrop near the stream channel of the gulch the quartz porphyry crosscuts the marker tuff bed at right angles to bedding. Some layers in the marker tuff are cut off abruptly and others can be traced several feet into the porphyry before all indications of their previous existence disappear. Where porphyry parallels bedding, the replacement of bedded layers by porphyry at transitional contacts may be difficult to prove, but in the upper Deception Gulch outcrop where porphyry intersects bedding at right angles, the gradual disappearance of bedding into quartz porphyry is a good example of metasomatic replacement which is probably an important process in the emplacement of quartz porphyry and quartz porphyry inclusions in the Jerome district (Evans, 1944).

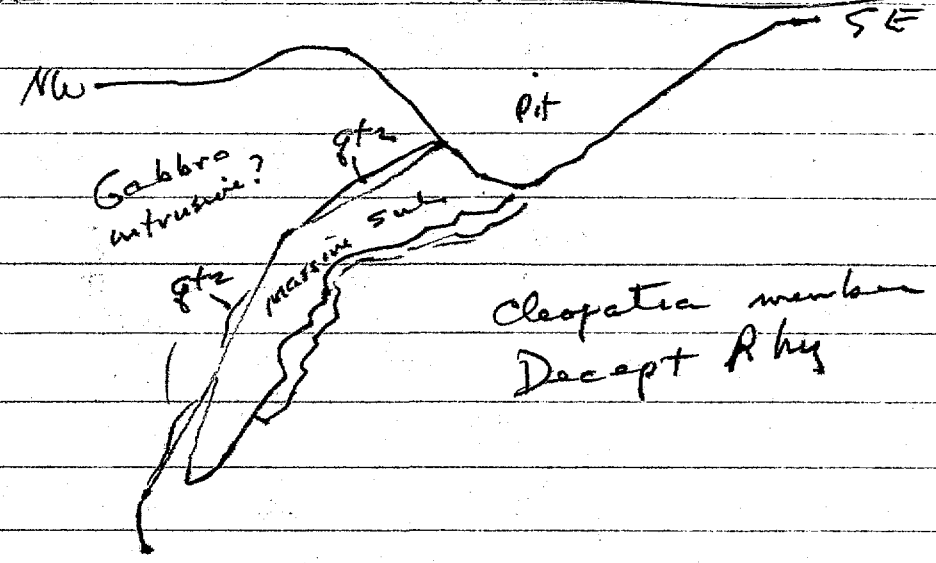
In sharp contrast to the evidence that the porphyry

Jerome

Anderson + Nash, Nov '72

Massive sul occurs (Py, cpy sph) as concordant stratabound lenses in submarine pyroclastics (crystal tuffs) — essentially syngenetic and related to hydrothermal brines discharged into submarine basin





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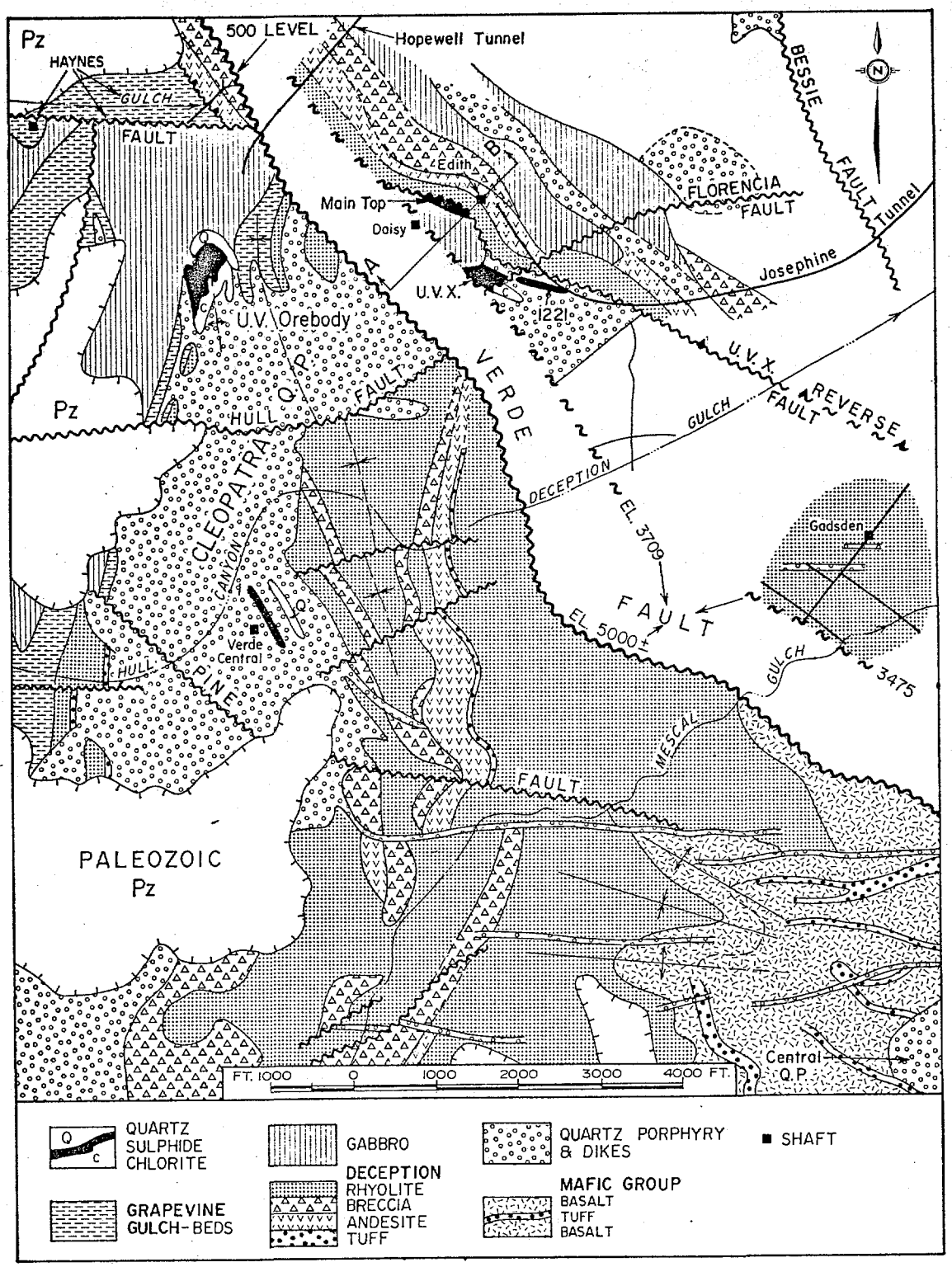

FIG. 2. Geology of the United Verde-U.V.X. mine area near Jerome showing surface geology west of the Verde Fault between Haynes and Mescal gulches and surface projections of underground geology east of the fault (from diamond drill hole Hopewell Tunnel, 12 to 17 levels U.V.X. mine and Gadsden mine).

bands. North of the Hull Fault alteration partly obliterates distinguishing characteristics of the different types of porphyry.

The Cleopatra, Central, and Southern Quartz Porphyry masses form a series introduced at successively higher levels in the regional structure. A breccia

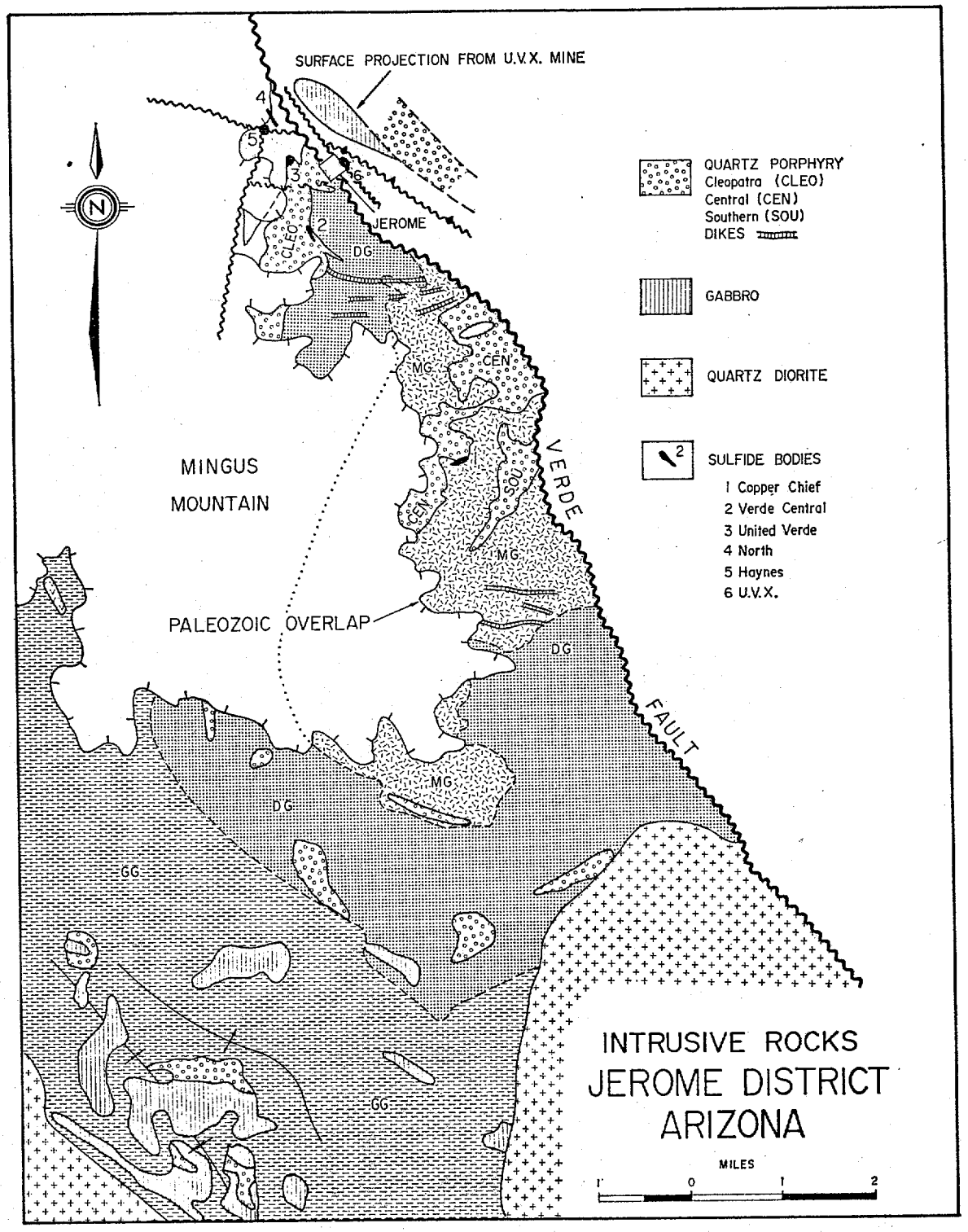

FIG. 3. Geological map, Jerome region, of intrusive rocks with areas underlain by stratigraphic units indicated; south half modified after Anderson and Creasey (1958).

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tensions of the porphyry and the gabbro terminate independently, the porphyry extending much farther south than the gabbro; in contrast, their eastern extensions terminate abruptly at the U.V.X. Reverse Fault. The east boundary of the Cleopatra Quartz Porphyry as shown on 1300, 1400, and 1700 Level maps is margined by Deception Rhyolite and forms a steep, east-dipping plane. The relationships shown on Level plans support the conclusion that the quartz porphyry is cut off eastward by the U.V.X. Reverse Fault, which lies along the west side of the rhyolite.

The east boundary of the gabbro in the U.V.X. mine also dips steeply east, about 80 degrees, approximately parallel to the reverse fault plane (Fig. 4). The east dip in the U.V.X. mine changes to a west dip away from the reverse fault on the west side of the Verde Fault in the United Verde mine. The gabbro, unlike the porphyry, is separated from rhyolite by a thin partition of phyllite which is probably derived from an eastward extension of Grapevine Gulch beds which enclose the gabbro west of the Verde Fault.

Sulfide mineralization and orebodies in the U.V.X. mine occur at intervals for nearly 3,000 feet along the Reverse Fault, in contrast to the United Verde Gabbro and Cleopatra Quartz Porphyry which extend eastward to end at the fault. The most southern occurrence was explored by a short drift from the Josephine haulage tunnel near the south boundary of the porphyry and about 100 feet southwest of the Reverse Fault. The most northern occurrence, the Main Top orebody, bottomed above the 1400 Level in phyllite between the northern part of the gabbro and the fault.

Ore, consisting of sulfides, oxides, and jasperoid with chalcocite, was mined at intervals in the upper levels for nearly 1,600 feet directly west of the Reverse Fault, from the Main Top orebody east of gabbro in the north to the 1221 stope in porphyry at the south (Fig. 2). The orebodies in this 1,600 foot zone parallel the fault if elongate like the 1221 stope or end eastward at boundaries parallel to the fault like the Main orebody on the 1200, 1300, and 1400 levels. The structural relationship of orebodies to the U.V.X. Reverse Fault in the U.V.X. mine is similar to the relationship of the United Verde Main and North orebodies to a strong zone of foliation in the United Verde mine (Anderson and Creasey, 1958). The occurrence of sulfide mineralization along the reverse fault in the U.V.X. mine indicates either fault control or a structural relationship produced by a common cause.

The relative ages of porphyry, gabbro, reverse faulting, and mineralization in the U.V.X. mine cannot be determined by observation due to the inaccessible state of the mine. The termination of the

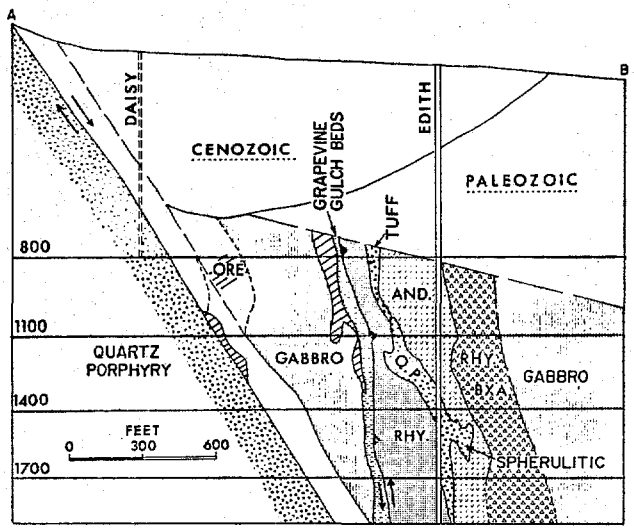

FIG. 4. U.V.X.—Mine Section A-B (location Fig. 2).

gabbro and of the porphyry at the Reverse Fault suggests that the quartz porphyry is older than the fault and that the gabbro if not older may be approximately contemporaneous. The mineralization is definitely younger than the porphyry and may be younger than, or contemporaneous with, the fault, which would make it younger than, or contemporaneous with, the gabbro.

Massive Sulfide Deposits

Introduction

Theories concerning the origin of the sulfide deposits in the Jerome district must account for their spatial and mineralogical relationships to enclosing rocks and structures. Sedimentary and volcanic horizons which form hosts to the deposits occur in the district's three major stratigraphic groups—the uppermost Grapevine Gulch Formation, the intermediate Deception Rhyolite, and the basal mafic volcanic group, which total a thickness of several thousand feet or more. The older theories (Reber, 1922) of ore genesis were based on observations during the mapping of fresh mine working faces that the gabbro and quartz porphyry which margin sulfide orebodies were intrusives and that they predated sulfide deposition. Recent interpretations, influenced by popular theoretical volcanogenic models, advocate syngenetic ore deposition with volcanic rocks prior to the intrusion of gabbro. The origin of some puzzling features along quartz porphyry contacts must be correctly solved before ore genesis at Jerome and many other localities is understood.

Distribution and host rocks

Stratiform and veinlike bodies of massive sulfide in the Jerome district are confined to an area ex-

THE ARIZONA GEOLOGICAL SOCIETY
MASSIVE SULFIDE DEPOSITS FIELD TRIP
JEROME-BRUCE-BAGDAD
FRIDAY, NOVEMBER 18
Overnight at Cottonwood

12 Reservations at View Motel, 634-2932, Cottonwood, 5 o'clock hold

The following assignments have been made:

S. R. Davis -- driver Sunday to Bagdad
J. H. Courtright
P. G. Vikre
G. W. Pickard

H. G. Kreis -- driver
R. B. Crist
~~D. M. Smith~~
J. L. Galey (Silver Bell)

B. J. Devere -- driver
G. J. Stathis
J. D. Sell
W. R. Hahman (Ariz. Bur. Mines)

Saturday, November 19, 8:00 AM, Clarkdale, Start of Field Trip
(Parking lot of Texaco Station/Cafe, uphill side of town)

Our reservations will be held until 5 PM on Friday and, although Lois will call to affirm that we are on our way, it is suggested that if your group will be substantially later then you should call and reaffirm your reservation.

Contact your driver for leaving arrangements or if you are not attending.

ARIZONA GEOLOGICAL SOCIETY
Saturday, November 19, 1977, Field Trip Meeting

This is the final announcement concerning the Massive Sulfide Deposits field trip--an organized tour of the Jerome-Iron King-Mayer areas.

MEET AT: Clarkdale, 8:00 a.m., parking lot of Exxon Station

EQUIPMENT: There will not be any open pit/underground tours, so hard hats and lamps are not necessary. Bring lunch and water.

CLOTHING: Anticipate cool weather. The field trip should end about 6:00 p.m., 1/2 mile hikes may be necessary at each stop. Wear appropriate foot gear and clothing.

NOTICE: An informal field trip to the Bruce-Bagdad area may be organized for Sunday, November 20, 1977 (approximately 1/2 day) if enough interest is shown.

SPECIAL NOTICE: Geologic papers on SE Arizona are now being solicited for the combined (A.G.S. & N. Mexico G.S.) Field Conference Mtg. of Fall-1978. See or call Charlie Miller (AMAX) for info.