Geochemical and Petrographic Investigation of the Jones Camp Magnetite Ores and Associated Intrusives Socorro County, New Mexico

by

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ABSTRACT OF THESIS

The podiform magnetite-hematite deposits of Jones Camp occur on the southern edge of Chupadera Mesa in western Socorro County, New Mexico. These lenticular, discontinuous pods of high grade ore occur adjacent to the Jones Camp monzodioritic dike and associated diabase dikes and sills replacing Permian sedimentary host rocks of the Yeso Formation (limestones, sandstones and gypsum).

The Jones Camp Dike forms a prominent ridge through the study area, measuring 600 feet (200 m.) in width and no less than 14 miles (22 km.) in length. The dike is a grey to pink, massive, intergranular to subophitic, quartz-poor hornblende-pyroxene rock which grades from a monzodiorite in the core of the intrusive to a diorite at its margins.

Field, petrographic and major element studies suggest that the zonational character of the dike is a result of multiple intrusions which can be related to a fractionating magmatic source.

The Jones Camp ore consists predominately of a fine-grained massive magnetite ore which shows extensive martitization. Other minerals in the ore include minor maghemite, pyrite, ilmenite and trace copper oxides.

Fourteen trace elements were determined in the ore and include Co, Mn, Zn, Cr, Ni, Cu, Ti, V, Mg, Ca, Pt, Au, Ag, and P. This data in conjunction with field and petrographic studies suggest that the ore was emplaced following consolidation of the Jones Camp Dike and associated diabase dikes and sills from a low temperature hydrothermal fluid which most likely derived iron from marginal zones of the Jones Camp Dike. The border facies of the Jones Camp Dike shows a significant enough depletion to account for the mineralization present at Jones Camp.

A determination was made of the precious metal content in the Jones Camp ore (including Ag, Au and Pt-group elements) which indicates that the Jones Camp ore holds no economic amounts of these metals.

ACKNOWLEDGEMENTS

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INTRODUCTION

Purpose and Scope

Field, petrographic and geochemical investigation of the Jones Camp Dike and associated ore deposits was undertaken for the purpose of better understanding their origin.

Location and Accessibility

The Jones Camp Magnetite Deposit lies within the Chupadera Mesa of south-central New Mexico, approximately 47 miles (76 km.) east of San Antonio (Figure 1). It is located north of U.S. Highway 380 extending along an east-west trend through township 5 south, ranges 6 east through 8 east. Its access is made easy via the old, although still maintained, Socorro-Carrizozo highway which parallels the Jones Camp Dike to the north. The deposit is also accessible by a series of ranch roads branching north from U.S. highway 380.

History of Ownership and Mine Production

The Jones Camp Magnetite Deposit, discovered in 1900, was named in recognition of Fayette A. Jones by a local

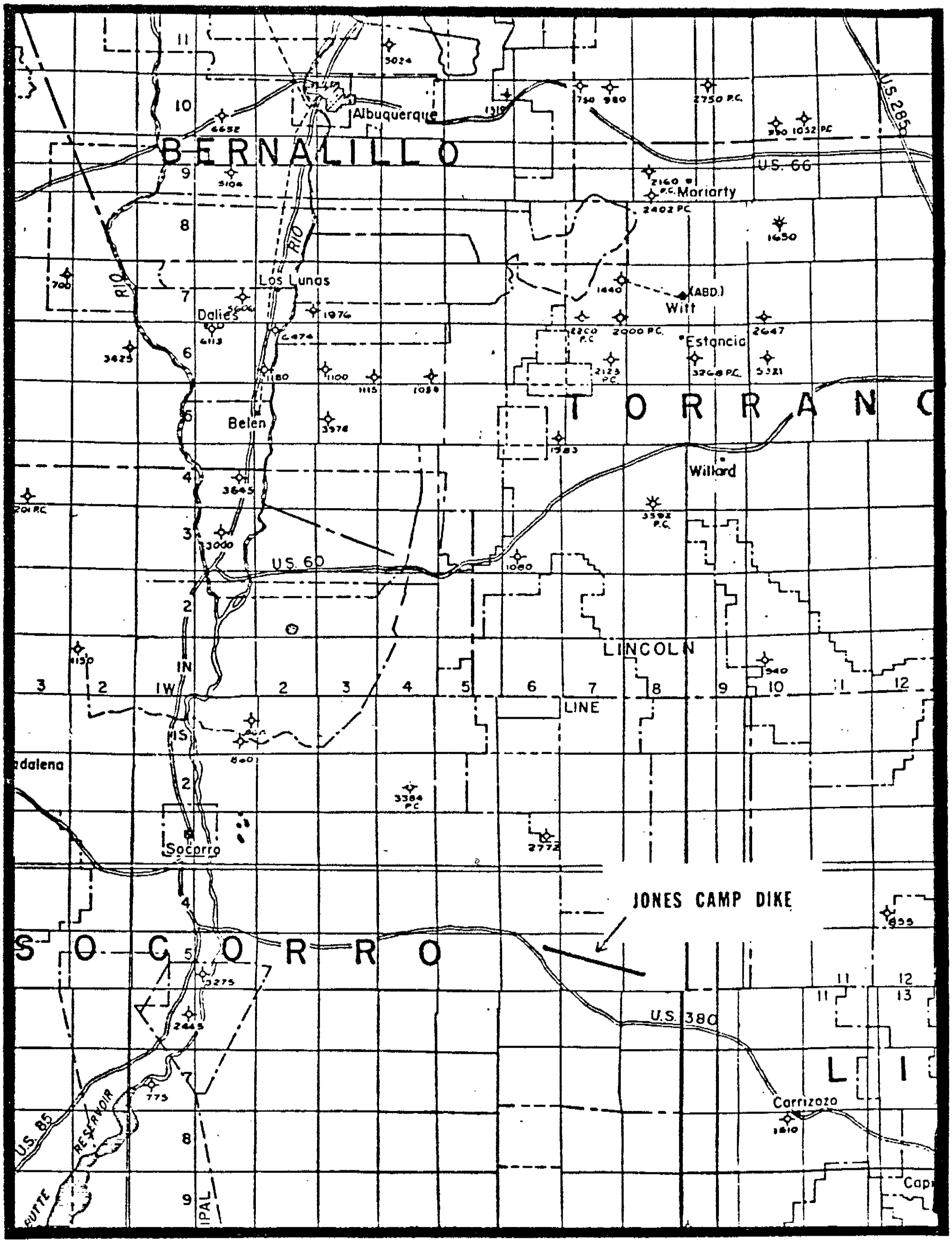


Figure 1. Map showing location of the Jones Camp study area.

prospector, P.G. Bell. Mining records show the first claims to have been established on the Jones property in 1927.

In 1964-65 Carl Dotson, of the International Mineral Company, Soccoro, acquired the rights to several lode and placer claims on the Jones property and was the first to begin mining operations since the deposits discovery. Between 1963 and 1969 some 100,000 tons of ore was removed from several pits in the central part of the deposit where substantial showings of iron ore are found. The ore was shipped to a local cement manufacturer where it was used in the production of high density cement. Less than 10,000 tons was mined by the same operation and sold as a water purifying agent.

Dotson sublet his claim in 1977 to Aweco International, LTD, the present operators and principal claim owners in the Jones Camp Mining District. To this date, no further ore has been mined however an extensive drilling program has been outlined along with plans for the building of a 500 ton/day billet mill once ore reserves have been proven.

Previous Work

Several early and brief accounts of the Jones Camp Deposit are found in the literature (Jones, 1904; Keyes, 1904; Emmons, 1906; Lindgren, 1910; Schrader, 1910; Darton, 1928; and Lasky, 1932) which furnish some perspective as to the geology and origin of the mineralization.

In 1942, with increased interest in iron ore during the Second World War, the United States Bureau of Mines, under the field supervision of R.M. Grantham, along with V.C. Kelly of the United States Geological Survey, conducted a detailed geologic investigation and reserve assessment of these deposits. Several test pits were excavated. One 30 foot (10 m.) down dip shaft constitutes the only subsurface exploration of the Jones Deposits. Cleveland Cliffs Drilling Company was contracted by Dotson in 1963 to drill several holes on the property however no information is available concerning results.

More recent investigations of these deposits were completed by Nogueira (1971) and Bickford (1980) as unpublished masters theses at New Mexico Institute of Mining and Technology. These papers provide more detailed geologic mapping as well as report results of detailed geochemical and geological studies.

Physiographic History and Topography

The Jones Camp Mining District lies on the southern edge of the Chupadera Mesa, a broad platform which rises to an elevation of over 6500 feet (2132 m.), some 1400 feet (460 m.) above the Jornado Del Muerto Basin to the west. To the south and southwest, the mesa is joined by the Oscura Mountains, a prominent ridge which is bounded to the west by a steep, westward facing scarp. The region is dissected by numerous alluvium filled valleys with the major drainage to the east and southeast.

Water is scarce and only obtained from deep wells. Vegetation is typical of the high desert country which supports cacti, juniper trees and grasses.

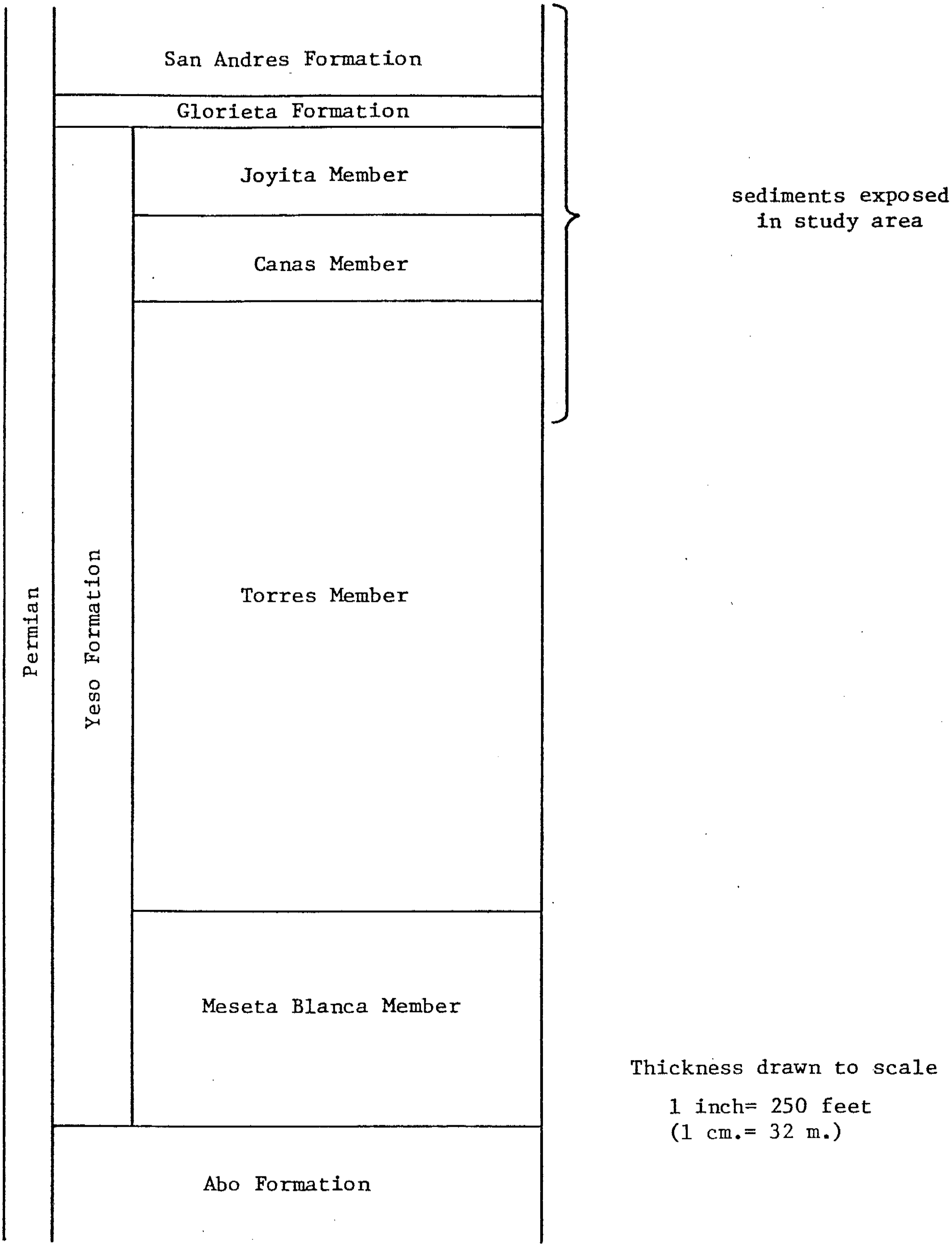
GEOLOGY

Stratigraphy

Permian sedimentary rocks exposed within the study area have been grouped into two or three formations depending upon whether previous authors considered the Glorieta sandstone to be distinctive and extensive enough to warrant formational status. It has been considered a lower member of the San Andres Formation (Read and Andrews, 1944), but in this paper the Glorieta will be considered a distinct formation following Hager and Robitaille (1919). Figure 2 is a stratigraphic column of the Permian formations found within the study area; these include, in ascending order, rocks of the Yeso Formation, Glorieta Formation, and San Andres Formation.

Yeso Formation

The Yeso Formation was first named and described by Lee (1909) for exposures at Mesa del Yeso near Socorro, New Mexico. Needham and Bates (1943) established a section and subdivided the Yeso into four members; the Meseta Blanca, the Torres, the Canas and the Joyita. Only the upper three members are exposed within the study area.



Thickness drawn to scale

1 inch= 250 feet
(1 cm.= 32 m.)

Figure 2. Stratigraphic section of Jones Camp and surrounding area (after Bickford, 1980).

Torres Member

Only the upper part of the Torres member is exposed along the Jones Camp Dike and it is best observed where the section has been more deeply eroded near the west end. Near the eastern end of the dike, the Torres member disappears beneath the overlying Canas member. The Torres member consists of interbedded limestones and gypsum with minor siltstones and sandstones. Bickford (1980) measured 200 feet (66 m.) of Torres member which contains three prominent limestone units ranging up to 30 feet (10 m.) in thickness each. The limestone beds consist of grey to black, finely laminated to thickly bedded, often gypsiferous limestone containing fossiliferous horizons and brecciated zones. They are interbedded with thickly laminated, bedded gypsum which in turn contains numerous, generally thin, siltstone and sandstone layers. The limestone units often crop out as prominent ridges along the base of the erosional scarps to either side of the dike. The top of the uppermost limestone unit marks the lower contact of the Canas member.

Canas Member

The Canas member is distinguished from the Torres by an increased abundance of gypsum as well as a decreased amount of interbedded siltstones and sandstones. Bickford (1980) measured 100 to 140 feet (33 to 46 m.) of Canas, 85% of which consists of laminated to thinly bedded, grey to white gypsum. Layers of grey, gypsiferous limestone up to a few feet (.7 m.) in thickness as well as minor, thin beds of siltstone and sandstone can be found intercalated with the gypsum. The Canas member shows little resistance to erosion and generally floors the valleys adjacent to the central dike region. Where contact between the Canas member and the Joyita member is exposed, the boundary is sharp and easily recognized.

Joyita Member

The Joyita member, because of its compositional homogeneity and distinctive reddish coloration, is the most easily delineated unit in the field area. It consists predominantly of a homogeneous, fine-grained, reddish, thinly to thickly bedded sandstone or feldspathic sandstone. Less than 15% of the 100 to 140 feet (33 to 46 m.) of Joyita exposed in the field area consists of a grey to white, thinly to thickly laminated gypsum. The top of the Joyita is marked by a 6 to 8 foot (2 to 2.7 m.) layer of gypsum which is often used in the field to locate the base of the Glorieta Formation. The contact is sharp and conformable.

Glorieta Formation

The Glorieta sandstone was first named by Keyes (1915) for Glorieta Mesa which lies just southeast of Santa Fe, New Mexico. The United States Geological Survey (Read and Andrews, 1944) considers the Glorieta to be the lower member of the San Andres Formation while other workers (Hager and Robitaille, 1919) regard the Glorieta as being a distinct unit deserving formational status; it is so considered here. The Glorieta Formation consists of a fairly homogeneous, medium-grained, thinly bedded, yellow-buff sandstone or feldspathic sandstone. Approximately 50 feet (16 m.) of Glorieta is present throughout the length of the dike. The San Andres Formation lies comformably above the Glorieta; the contact is sharp and usually well exposed.

San Andres Formation

Lee (1909) first described the San Andres Formation from its type locality in the San Andres Mountains of south-central New Mexico. It consists of a grey, thickly bedded, fossiliferous limestone with abundant ferruginous chert nodules. The San Andres forms the resistant cap which supports the prominent cuestas to either side of the central dike. Minor sandstone layers resembling the Glorieta sandstone are included in the nearly 150 feet (50 m.) of San Andres Formation exposed in the study area.

Igneous Rocks: Field Relationships and Petrography

Two types of igneous rocks crop out in the study area; the central monzonite-diorite dike (the Jones Camp Dike) which extends along the length of the study area in an east-west direction and the numerous diabasic sills and dikes which border the central dike to the north and south. The association of iron ore with the various intrusives in the area has been discussed by Nogueira (1971) and Bickford (1980); however the importance of this relationship in terms of understanding the origin of the mineralization warrants more detailed investigation of these intrusives.

The Jones Camp Dike

The Jones Camp Dike is the prominent intrusive body in the field area. It measures an average of 600 feet (200 m.) in width and can be traced for at least 14 miles (22.5 km.) in a N 75 W direction. The dike was first described in detail by Nogueira (1971) who subdivided the dike into several facies based on field relationships, mineralogy, textures and major element content. His data was collected from several exposures within his detailed study area shown on the accompanying map (Plate 1b). Nogueira concluded that the dike was of a composite nature, formed by multiple intrusions.

Because an understanding of the nature of the Jones

Camp Dike may be important in evaluating the origin of the mineralization, the present study expands upon Nogueira's work to include a similar investigation of two good exposures across the dike, also shown on the accompanying map (Plate 1b). Based on these studies, three models will be considered for the origin of the Jones Camp Dike:

1. The present zonational character of the dike is the result of post-dike alteration affects.

2. The dike is a composite dike in which facies development can be attributed to multiple intrusions.

3. The dike differentiated in situ to give rise to its present zonation.

Field Observations

The Jones Camp Dike forms a prominent ridge through the center of the field area. Its weathered surface is typically pink or grey to pale green and the depth of weathering seems to be locally controlled by the occurrence of joints which are best developed near the dike's border. They are probably related to cooling. Where joints are closely spaced paralleling the dikes border, the susceptibility of the dike to weathering is more pronounced, resulting in a rock which crumbles easily with the slightest pressure. The overall texture across the dike grades from a fine-grained or sometimes aphanitic border to a coarsely crystalline core.

Border Rocks

Nogueira (1971) describes the border of the dike as a distinct facies which ranges from 50 to 100 feet (16 to 33 m.) in thickness. It is typically a pale green, very fine-grained, deeply weathered rock which is characterized by a porphyritic appearing texture. Because of this texture, Nogueira describes this facies as the "mottled border facies". The nature of this texture is unclear since these two to three mm. spheroids are composed entirely of secondary minerals, principly tremolite. They are likely a replacement of plagioclase phenocrysts (Plate 2).

The border of the Jones Camp Dike is host to later, small discontinuous dikes and breccia zones (Plate 3) which parallel the dike's border and are probably related to the development of joints during consolidation of the dike (Smith, pers. comm., 1981). These intrusives which range up to a foot (.3 m.) in width form a braided network containing abundant fragments of the Jones Camp Dike and adjacent limestone. They are very fine-grained and pale green, lack a porphyritic texture and are more closely related in appearance to the numerous dikes and sills which are

Plate 2. Mottled texture common to the border facies of the Jones Camp Dike.

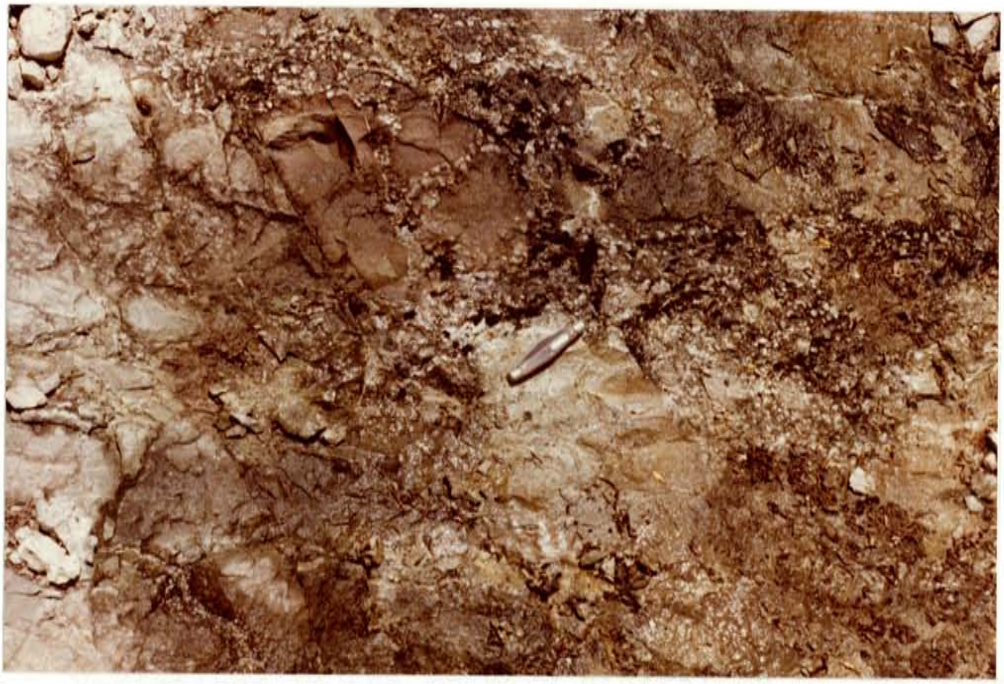


Plate 3. Picture shows a network of dikes or veins which intrude the border facies of the Jones Camp Dike. Intrusion of these late stage dikes along the interface between the central dike and adjacent limestone is suggested by the presence of both types of fragments (occurring as xenoliths) in the late stage intrusive.

peripheral to the central dike.

Secondary effects on these fine grained border rocks have destroyed much of the primary mineralogy so that in hand specimen, interpretation is made difficult.

Central Rocks

The primary mineralogy and texture of the coarser grained central rocks is relatively free from secondary effects (i.e. cross cutting dikes and alteration). They consist of a pink to grey, massive quartz-poor hornblende-pyroxene monzonite or diorite with generally less than ten percent orthoclase and scattered megacrysts of quartz which appear to be secondary. A few percent of magnetite and/or specular hematite occur throughout this rock. Tremolite, actinolite and sphene are the dominant secondary minerals present. Variations in the primary mineralogy of the dike´s central core is gradational and is generally the result of fluctuations in the relative abundance of pyroxene and hornblende. Nogueira (1971) used similar observations to delineate distinct facies, symmetrically developed about the dike´s center. The present study suggests that such trends are locally only vaguely developed and cannot be extended beyond the boundaries of Nogueira´s field area. The contact relationship between adjacent "facies" is quite gradational mineralogically, lacking any correlation between the transition in mineralogy and variation in grain size.

Adjacent "facies" show no apparent cross cutting relationships nor any inclusions of one "facies" within another (with the exception of the border facies) which would indicate multiple events.

Petrographic Observations

A total of 21 thin sections from the Jones Camp Dike were studied; detailed descriptions are found in the appendix. These thin sections were prepared from two suites of rocks collected from Section 24 and Section 18 detailed study areas in township 5 south, range 7 east (Figures 3 and 4). Modal analyses of twenty one sections were performed with the aid of a Swift Automatic Point Counter. Approximately 800 points were counted for each slide.

General Observations

The bulk of the Jones Camp Dike is a medium to coarse-grained, grey to pink massive intergranular to subophitic quartz-poor hornblende-pyroxene monzonite or diorite. According to Streckeisin (1966), the distinction between monzonite and diorite is based upon the quantity of plagioclase as a percentage of total feldspar. In general, the orthoclase content of the Jones Camp Dike is less than twenty percent, making this rock a monzodiorite or diorite.

Figures 5 and 6 show the trend in mineralogy across the

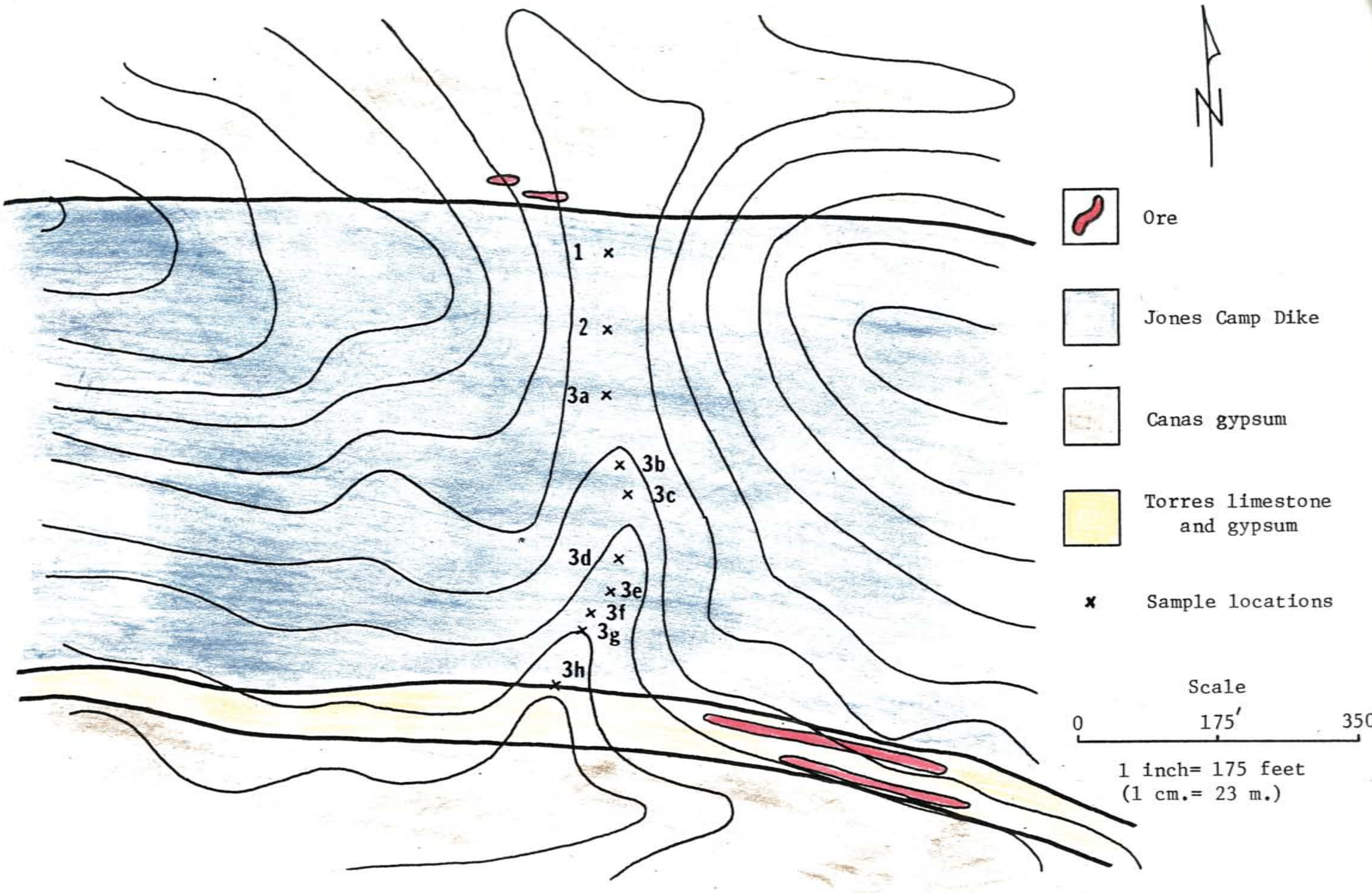


Figure 3. Section 24 detailed study area.

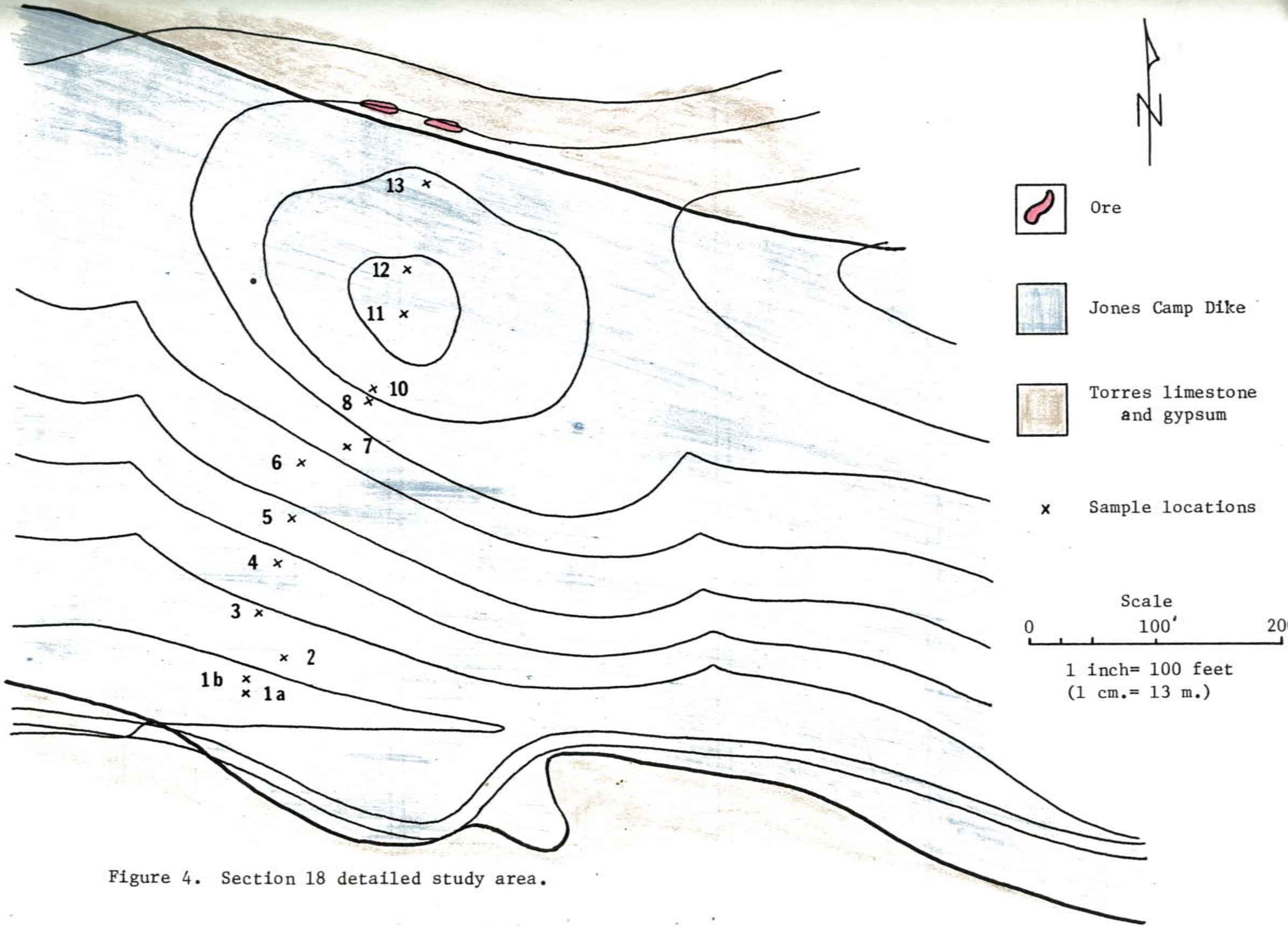


Figure 4. Section 18 detailed study area.

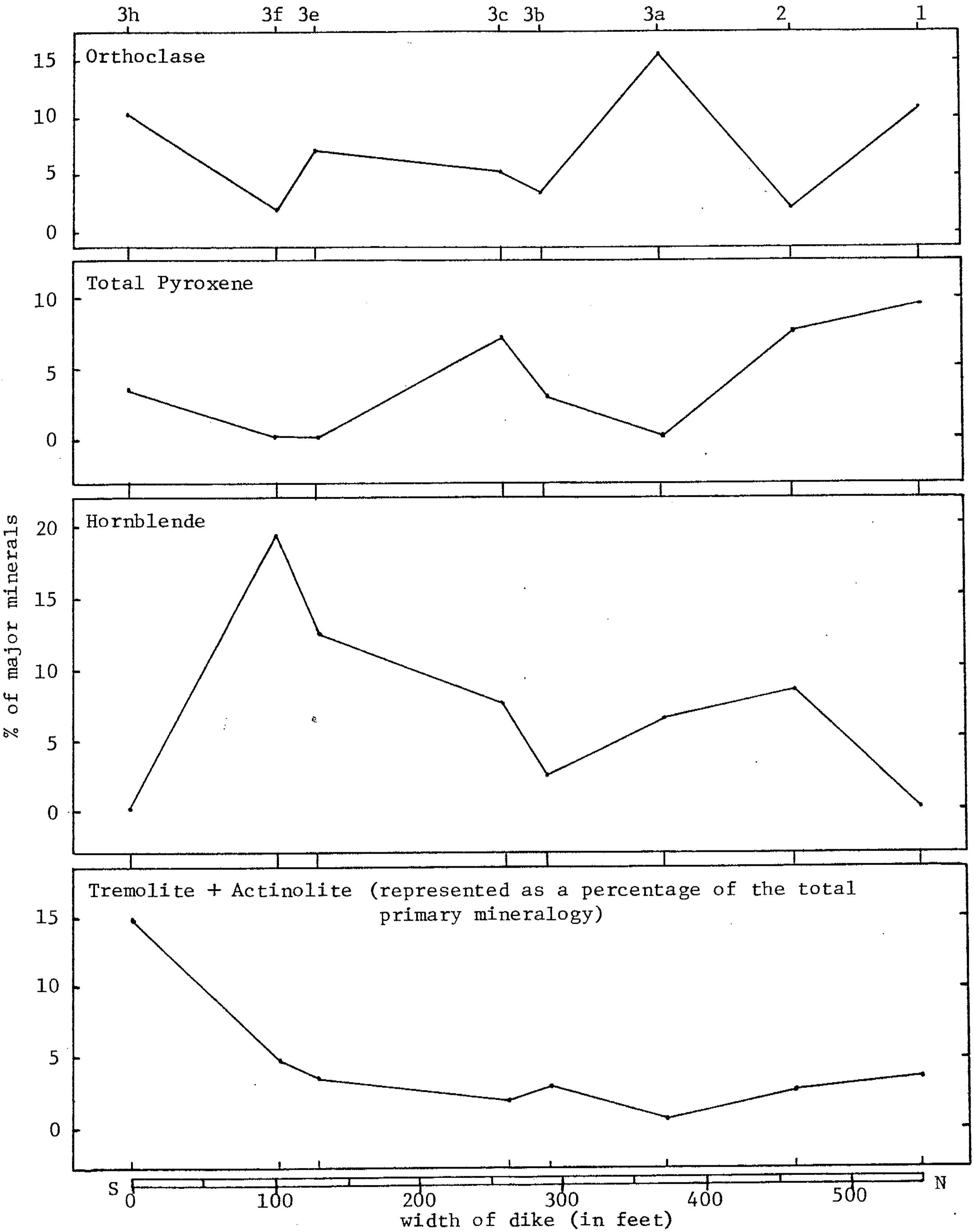


Figure 5. Variation in major mineral content across the Jones Camp Dike in the section 24 detailed study area.

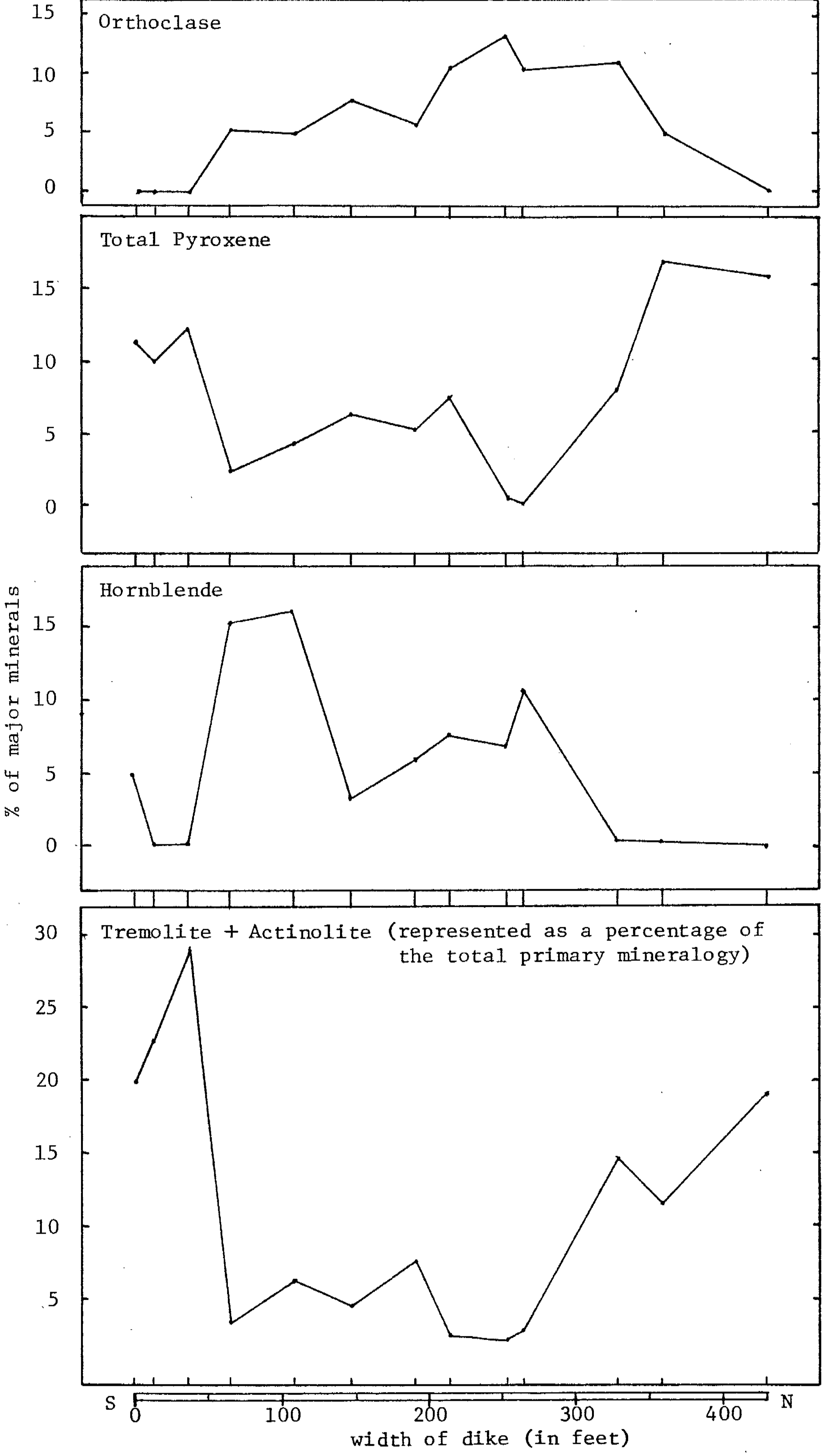


Figure 6. Variation in major mineral content across the Jones Camp Dike in the section 18 detailed study area.

dike based on modal analyses of rock suites from Section 24 and Section 18 detailed study areas. The abundance of tremolite + actinolite represents a percentage of the total primary mineralogy.

Although field observations fail to show any obvious facies development in the dike, some trends in the mineralogy across the dike are indicated from modal analyses:

1. Total pyroxene shows a W-shaped distribution, increasing towards the dike's border and center.
2. Hornblende shows a reciprocal trend from pyroxene, decreasing towards the dike's center and edge.
3. Orthoclase shows a general increase towards the dike's center.
4. Secondary minerals show a substantial increase at the dike's edge.

The most apparent trend in the primary mineralogy across the dike is that of an increasingly more mafic border, an observation that was also noted by Nogueira (1971). Another significant observation in the bulk mineralogy of the dike is that secondary minerals form a significant fraction of the dike, particularly along its margins. Since secondary effects may change pre-alteration trends, the extent of its influence is of considerable importance in understanding the origin of the dike.

Secondary Alteration of the Jones Camp Dike

The Jones Camp Dike has undergone significant changes in its mineralogy; portions of the dike are so intensely altered that few clues of its primary mineralogy remain. Secondary minerals commonly developed in the dike include tremolite, actinolite, calcite, sphene, albite, quartz, and hematite. Those which are less common include epidote, chlorite, olivine and sericite.

Tremolite and actinolite occur throughout the dike, comprising in some cases nearly sixty percent of the dike rock. In the border rocks these minerals occur as large masses which often replace minerals indiscriminantly. Although the dike's interior shows extensive secondary effects, tremolite and actinolite occur as finely divided, incomplete replacements which do not deter from primary mineral identification. In the central part of the dike tremolite most commonly replaces plagioclase (Plate 4) while actinolite and opaque minerals were commonly found replacing pyroxene, hornblende and biotite.

Sericite is a common constituent in plagioclase

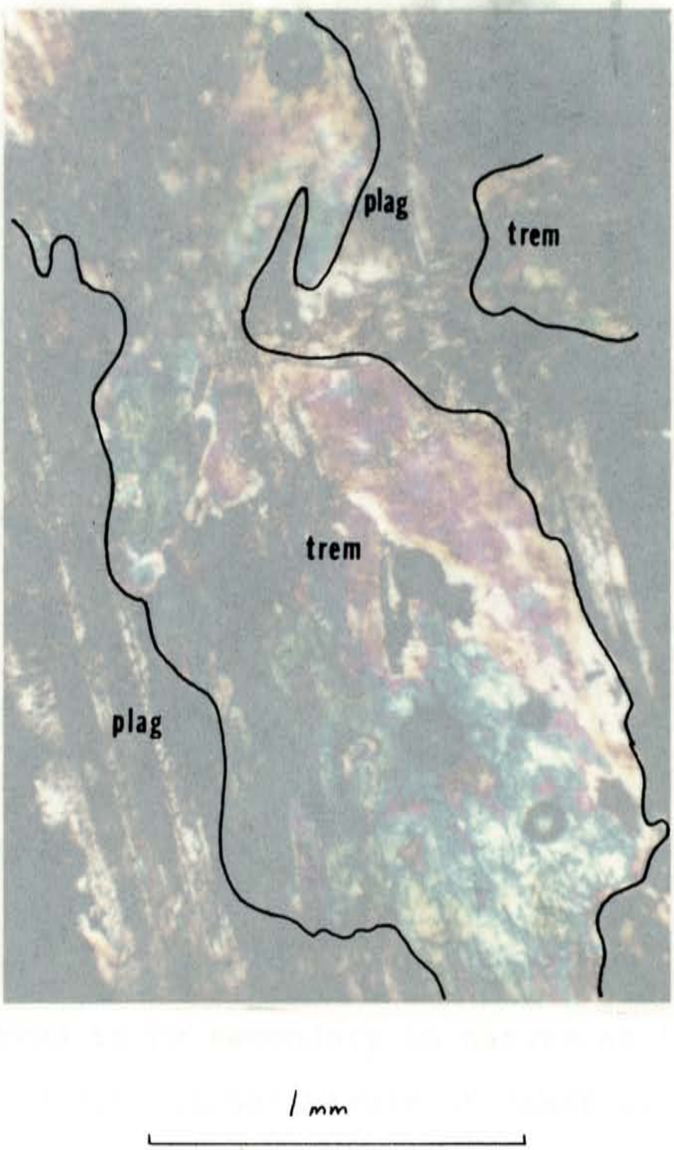


Plate 4. Photomicrograph showing extensive replacement of a plagioclase lath by tremolite and minor sericite. Nicols crossed.

alteration however due to its fine grained nature it was generally excluded from modal analyses. Sericite and tremolite are common products in the alteration of feldspars and are undoubtedly the chief replacement minerals where alteration products are too fine to recognize (Plate 5).

Albitization of plagioclase is also common in minor amounts throughout the dike, generally making up less than one percent of the rock although occurring up to two percent in a few sections. Albite is most commonly found in the rims of zoned plagioclase crystals where the anorthite content is considerably lower and less susceptible to other types of alteration.

Calcite occurs principally as microveinlets and vug fillings although it is sometimes seen as an alteration product of plagioclase (Plate 6) or replacing clinopyroxene. Like tremolite and actinolite, it occurs most often in border rocks.

Quartz rarely makes up more than a trace of the dike rock and is believed to be secondary in nature as it is most commonly associated with larger masses of other secondary minerals (Plate 7).

Sphene (titanite) is a common secondary mineral, often occurring in association with magnetite. One modal analysis indicates 4.5 percent sphene although most samples contain roughly one percent. Plate 8 shows a magnetite crystal with well developed exsolution lamellae (probably ilmenite) which have altered to sphene.

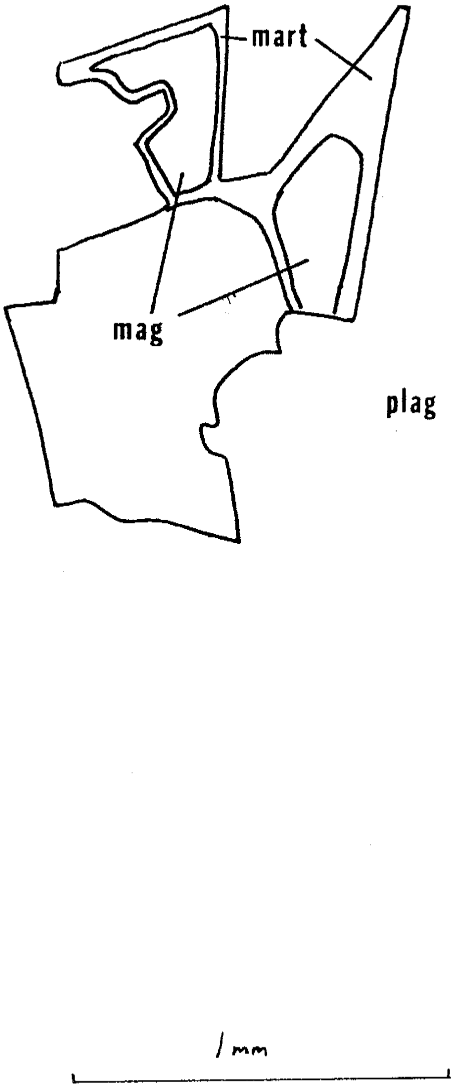


Plate 5. Interstitial magnetite surrounded by zoned plagioclase. Ca-rich plagioclase cores are extensively saussuritized while magnetite rims have altered to martite. Nicols crossed.

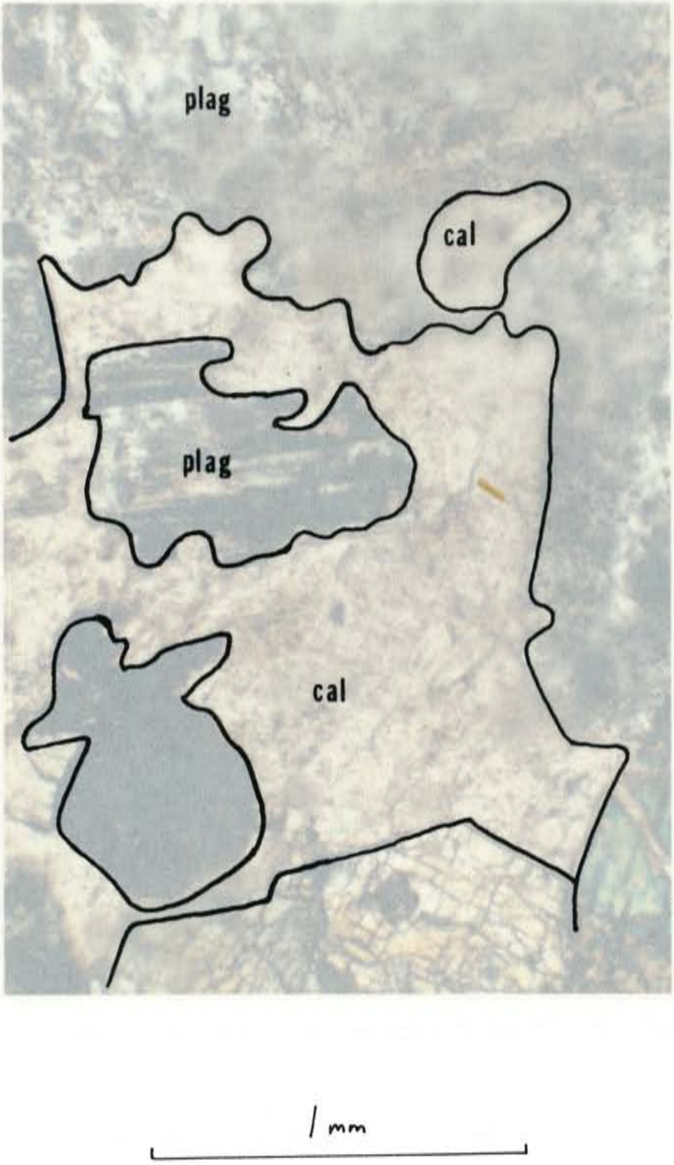


Plate 6. Photomicrograph showing extensive replacement of plagioclase by calcite. Nicols crossed.

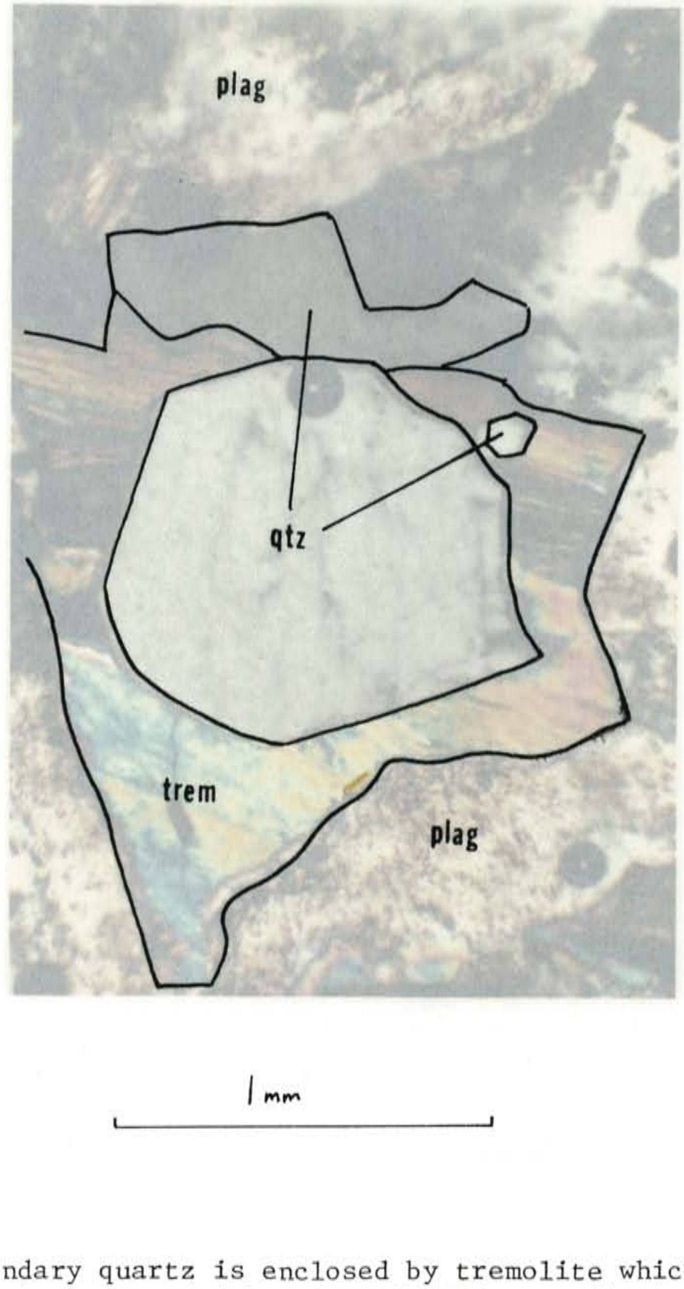


Plate 7. Secondary quartz is enclosed by tremolite which in turn is surrounded by altered feldspar. Nicols crossed.

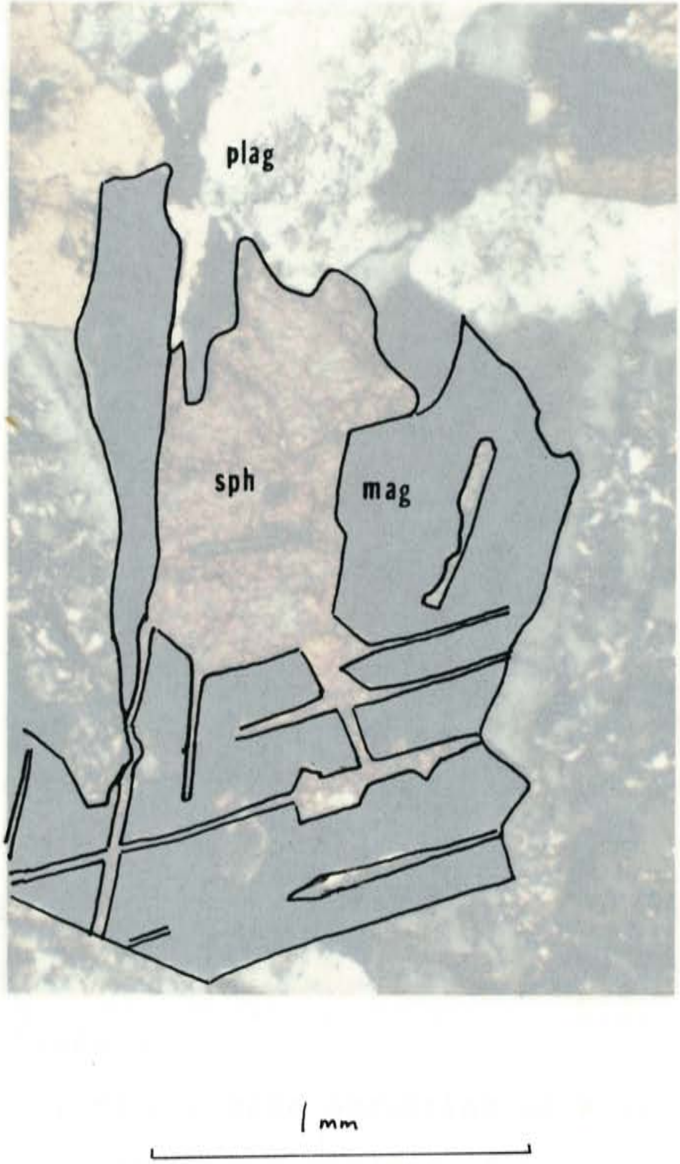


Plate 8. Accessory magnetite in Jones Camp Dike showing relict ilmenite lamellae which have altered to sphene. Nicols crossed.

Hematite generally occurs as a fine dusting among altered ferromagnesian minerals. Its abundance was measured by visual estimation, rarely composing more than three percent of any thin section.

Olivine is encountered infrequently; however according to Kerr (1959) olivine (forsterite) is a common constituent in contact metasomatic zones. It occurs as sparse, large euhedral crystals (Plate 9).

Epidote and chlorite are not commonly observed in the Jones Camp Dike although may be more abundant than is readily apparent within the finer grained altered groundmass.

Alteration of pyroxene to hornblende is a common, though minor occurrence throughout the dike. In general, replacement was only partial so that the trends we see in the distribution of pyroxene and hornblende across the dike are not the result of secondary effects. Most hornblende occurs as long needles or large euhedral crystals which are unquestionably primary.

The possibility of pyroxene occurring as a secondary mineral, particularly along the borders of the dike within the "mottled border facies" in unlikely since its subophitic to interstitial texture is well developed. Had it been secondary in nature, its occurrence would undoubtedly have been erratic.

How well we can interpret the primary mineralogy of the Jones Camp Dike is a function of how well we can see through

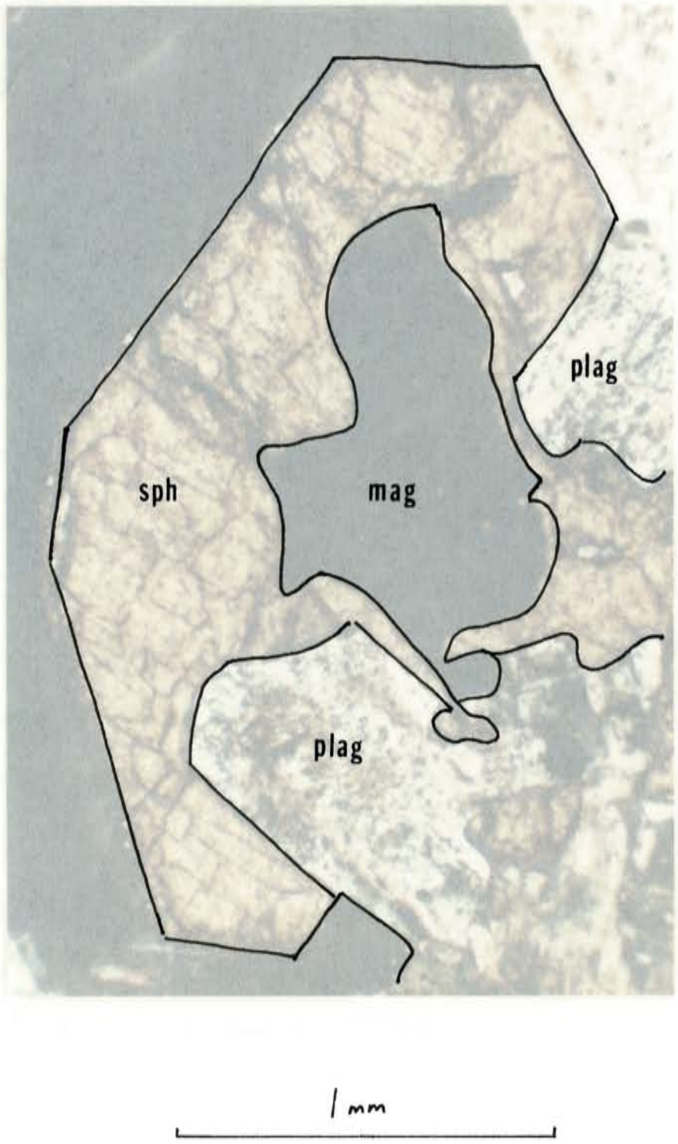


Plate 9. Euhedral crystal of secondary olivine(forsterite) within the Jones Camp Dike. Olivine is generally observed within open spaces in rock. Nicols crossed.

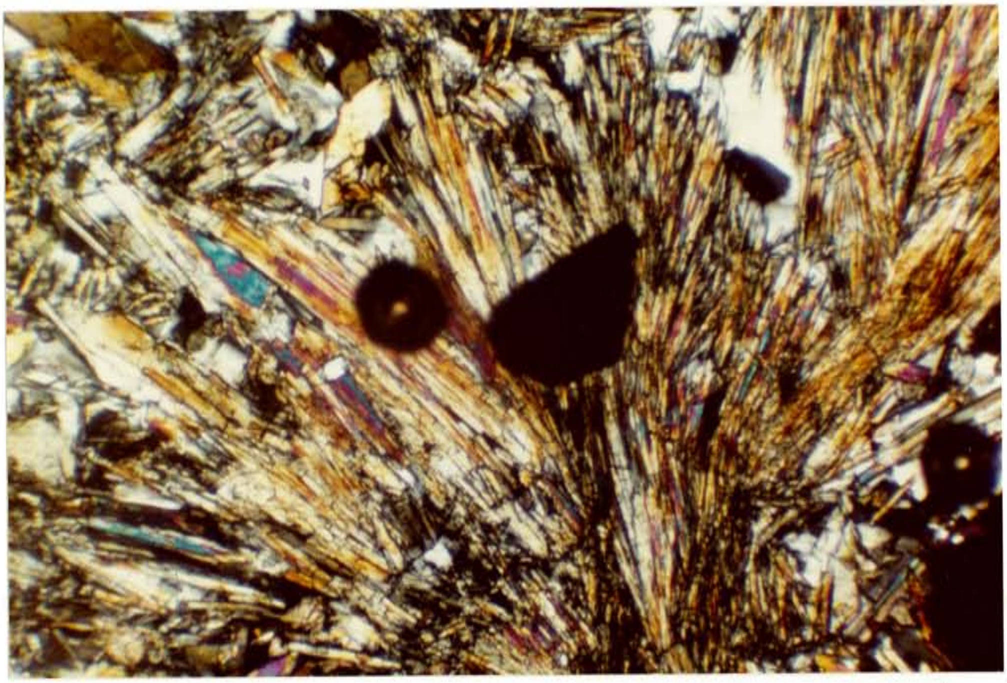
the secondary overprint. By far, tremolite and actinolite alteration is most responsible for obscuring the primary mineralogy, particularly within 50 to 100 feet (16 to 33 m.) of the dike's edges.

The primary mineralogy of the central rocks is still well preserved so that modal trends are representative of pre-alteration trends. Border rocks are considerably more altered, containing massive replacements of tremolite and actinolite (Plate 10). Interpretation of the primary mineralogy of these rocks is considerably more difficult so that modal analyses are probably somewhat less representative of pre-alteration trends.

Trends observed in the central rocks support our initial, fundamental observation that a felsic core grades into a more mafic border. Where the border rocks contain fifty or sixty percent secondary minerals, the primary mineralogy is quite obscured, making projection of these trends into the highly altered border rocks quite difficult.

Diabase

The numerous fine-grained dikes and sills which occur adjacent to the Jones Camp Dike have been described by Kelley (1949) and Nogueira (1971) as diabase while Bickford (1980) refers to these intrusives as a pyroxene syenodiorite. Field observations show these intrusives to be similar in texture and appearance to the border facies of



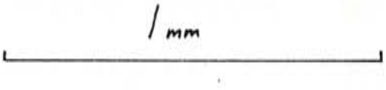


Plate 10. Radiating fibrous mass of actinolite indiscriminately replacing minerals of the fine-grained border facies of the Jones Camp Dike. Nicols crossed.

the Jones Camp Dike. Because these dikes and sills are strongly associated with the dikes border, it is often difficult to discriminate between the two.

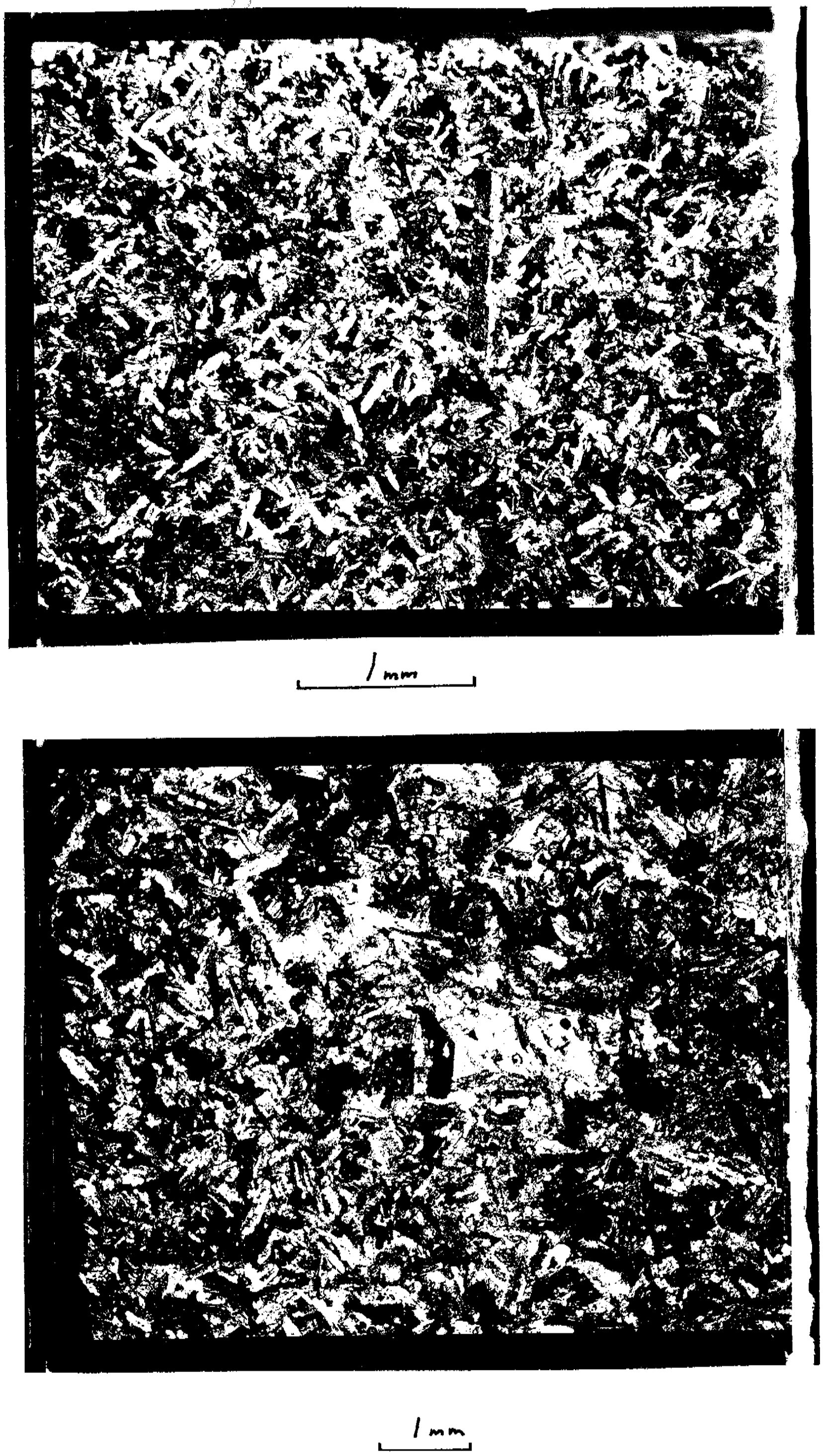
The diabase consists of a greenish to pink, fine grained, quartz-poor rock whose principal mafic constituent is pyroxene. In Plate 11 the diabase looks quite similar to the border facies of the Jones Camp Dike, although much less altered. Actinolite and tremolite occur throughout the diabase, however the primary mineralogy and texture is generally intact.

Field evidence shows the relative age of the diabase intrusives to be younger than the Jones Camp Dike. Diabase can be seen intruding the border facies of the Jones Camp Dike in the section 24 detailed study area. Inclusions of the border facies are clearly visible within a fine-grained diabase host (Plate 12).

Another reason for suggesting this age relationship can be seen in the rocks secondary texture. Border rocks of the Jones Camp Dike are extensively altered, displaying a ubiquitous mottled texture. This texture is absent in the diabase intrusives which are considerably fresher.

Bickford's (1980) findings are in agreement with the present author where he shows evidence of a chilled pyroxene syenodiorite in contact with the Jones Camp Dike.

The nature and abundance of primary magnetite in the diabase intrusives is not significantly different from the Jones Camp Dike, ranging up to a few percent. Secondary



Plates 11a,b Photomicrographs comparing fine-grained, unaltered texture of the diabase (above) with fine-grained, altered diorite; typical of the border facies of the Jones Camp Dike. Crossed nicols.

Plate 12. Border facies of the Jones Camp Dike which has been inundated with late stage intrusives. Fragments of the dike can be seen cemented by these smaller late stage dikes which are closely related in appearance to the numerous diabase dikes and sills in the field area.

magnetite is often significantly higher where diabase is in contact with magnetite ore. This has been the result of the introduction of large amounts of calcium carbonate into the diabase, probably incorporated during the dike's emplacement against host limestone. The calcite in the diabase was subsequently replaced by magnetite (Plate 13). Secondary magnetite also occurs as a fine dusting throughout the rock.

Ore: Field Relationships and Petrography

Field Relationships

Bickford (1980) first revealed the extensiveness of the Jones Camp ore by detailed mapping and magnetic surveys along the length of the central dike. Numerous similarities exist among the many pods of ore, suggesting a common origin for the mineralization:

1. Individual pods rarely exceed 12 feet (4 m.) in width.

2. Most pods have a length of 100 feet (33 m.) or less although some can be traced nearly continuously in outcrop or by geophysical means for up to 1000 feet (330 m.)(Bickford, 1980).

3. The ore is almost exclusively restricted to

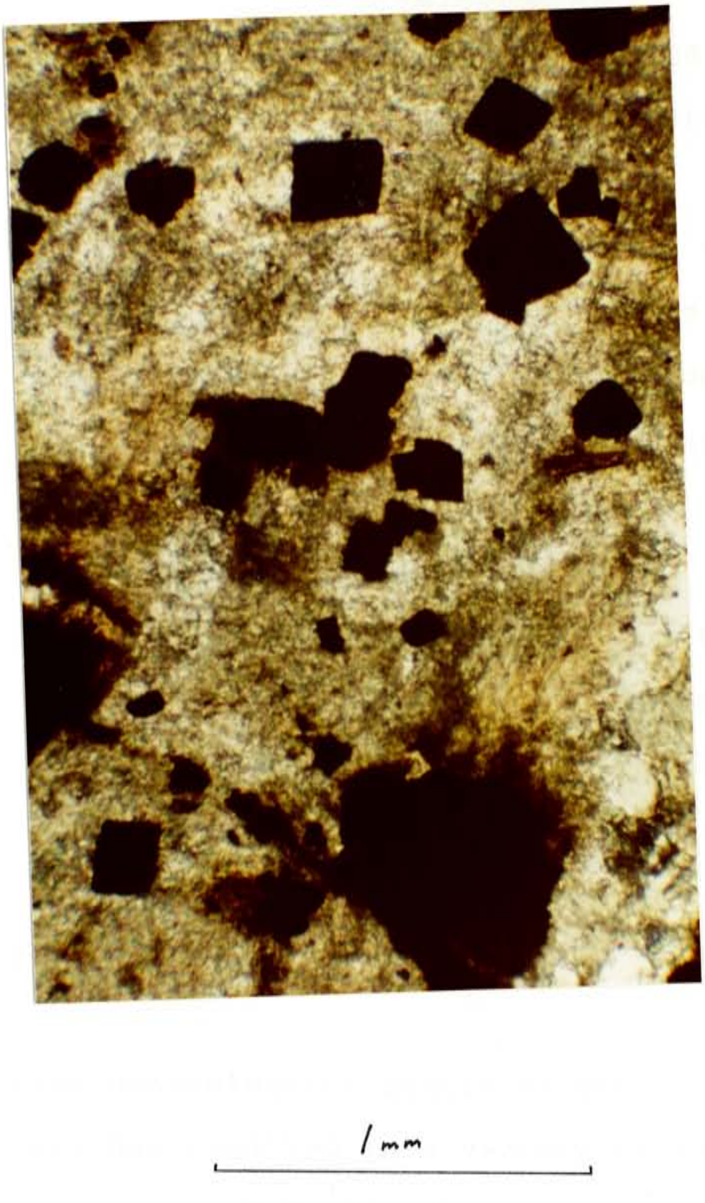


Plate 13. Octahedral magnetites replacing calcite. Sample was collected in the border facies of the dike where limestone fragments are believed to have been incorporated into the monzonite or diabase upon intrusion. Plane light.

rocks of the Torres member of the Yeso Formation, although minor showings occur elsewhere within the Yeso, Glorieta and San Andres Formations.

4. A non-selective association of the ore (with respect to the lithology of its host rock) is evident by its occurrence in limestone, sandstone and gypsum.

5. Ore minerals include magnetite, with lesser amounts of hematite (principally martite) and only very minor occurrences of maghemite, pyrite, ilmenite and copper oxides.

Contact Relationships Between Ore and Host Rock

The apparent non-selective nature of ore, with regard to its host rock, has resulted in a variety of textures and contact relationships. Where limestone has been the host rock, the ore is typically very fine grained, massive and pure. Because the limestone has usually been completely replaced, no pre-ore textures remain which might have indicated the manner of emplacement. The contact between unreplaced limestones and ore is very sharp (Plate 14) possibly indicating a marked change in the nature of the limestone (i.e. chemical or textural).

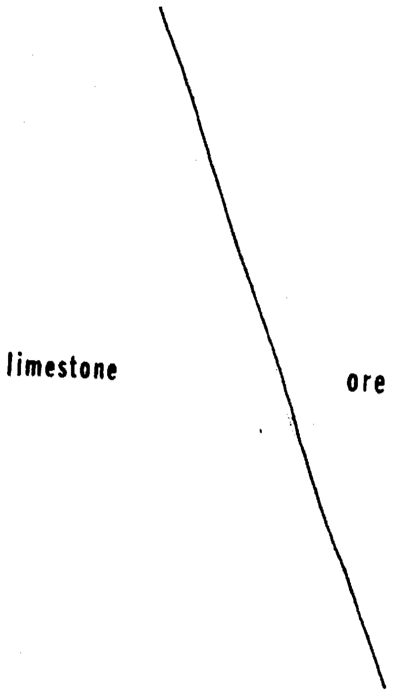


Plate 14. Sharp contact between magnetite ore and limestone.

Where sandstone has been the replaced rock, the contacts are generally quite gradational (though sometimes very sharp), resulting in an ore of variable grade (Plate 15). Bickford suggests that sandstone with a calcareous cement made an excellent host rock for the ore. The diffuse boundary between massive ore and unreplaced sandstone may be a function of this property.

Minor occurrences of breccia or vein ore can be found within replaced sandstone (Plate 16). A coarser texture and often only partial replacement of the sandstone suggests that solutions were responsible for much of this mineralization.

Replacement of gypsum often results in an ore which is quite gypsiferous and somewhat less desirable in terms of marketing potential. It is generally inundated with veins and fine disseminations of gypsum and may range in grade from a few percent iron to nearly pure ore which is characteristically vuggy; often displaying coarse, euhedral mineral development (Plate 17). This ore is occasionally host to very small quantities of pyrite near the ore-gypsum contact.

Intrusive rocks are generally free from ore replacement except within a few centimeters of the contact. Magnetite veins penetrating the dike′s border facies are occasionally observed (Plate 18).

In general, replacement textures suggest that at least some mineralization, particularly within the more porous

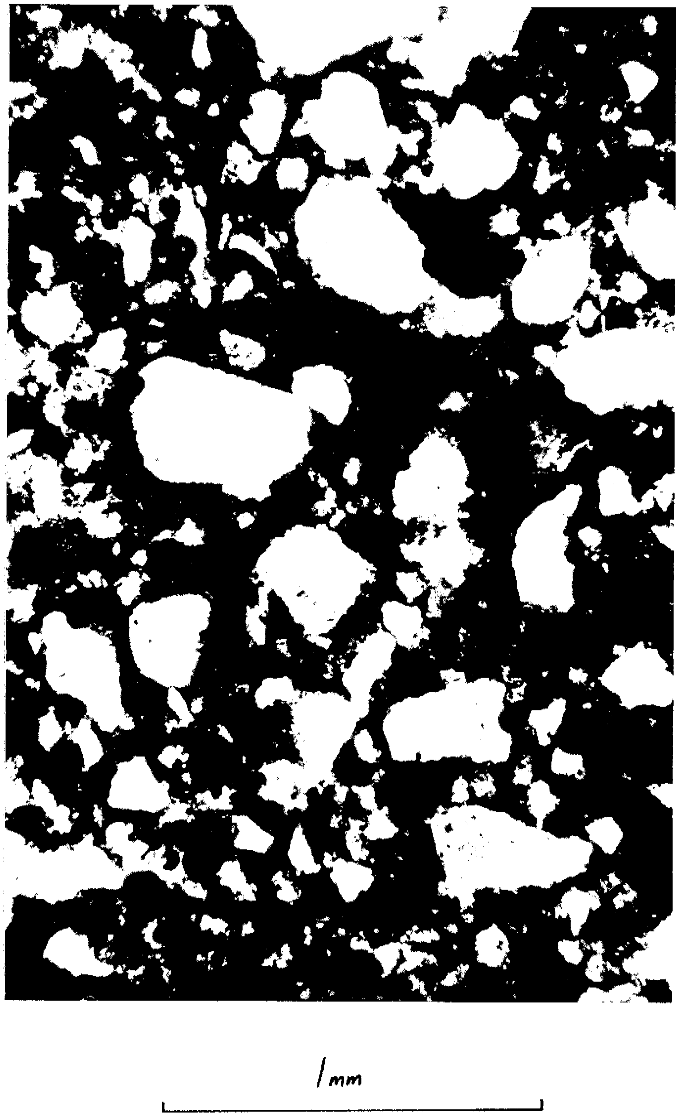


Plate 15. Photomicrograph showing partial replacement of sandstone by magnetite near the ore-sandstone contact. Plane light.

Plate 16. "Ore breccia" or vein ore within replaced sandstone.

Plate 17. Magnetite replacing gypsum often results in vuggy texture where coarse, euhedral mineral development is common.

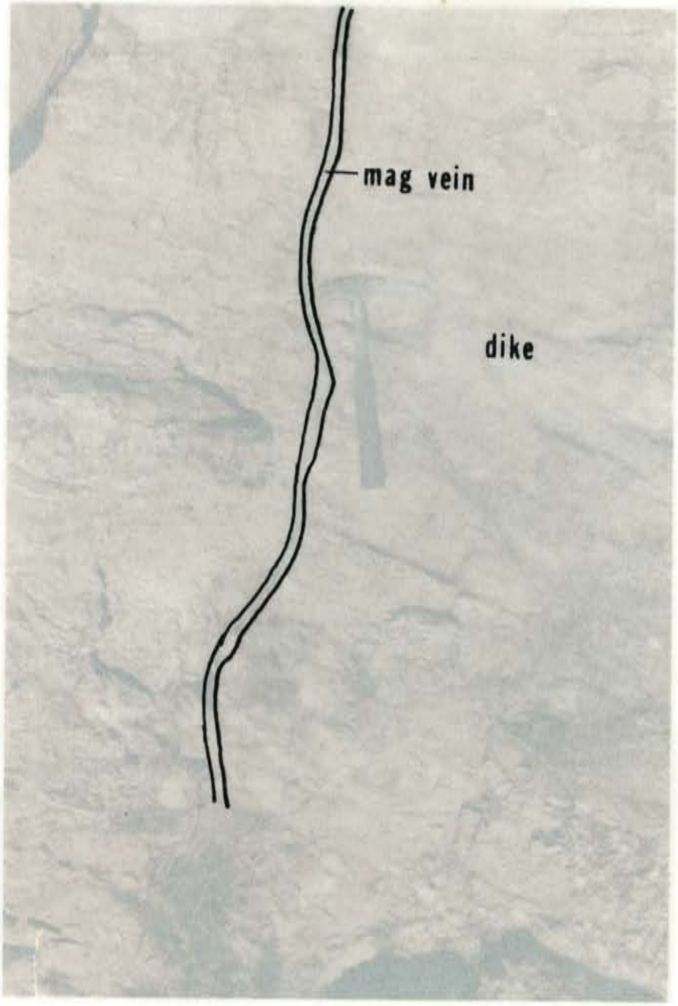


Plate 18. Small magnetite dike penetrating the border facies of the Jones Camp Dike.

sandstone and vuggy gypsum, is related to hydrothermal processes.

Petrographic Observations

Seventeen polished sections of the ore were described and are included in the appendix. Sample locations are indicated on the accompanying map (Plate 1b).

General Description

Ore samples were collected from numerous locations in various types of lithologic settings (i.e. at dike-limestone contacts, at dike-sandstone contacts, at dike-gypsum contacts and where dike rock appears to have been the host). Each petrographic description in the appendix indicates the host rock for the ore when known.

Jones Camp ore is typically a very fine-grained, massive magnetite ore which always shows some degree of martitization of magnetite crystals developed along crystallographic planes or as massive replacements (Plate 19). Two to fifteen percent martite is typical although some samples contain as much as seventy percent Fe_2O_3. Where this is the case, it is not known whether the hematite is a primary constituent or a result of alteration. Coarser grained samples occur where:

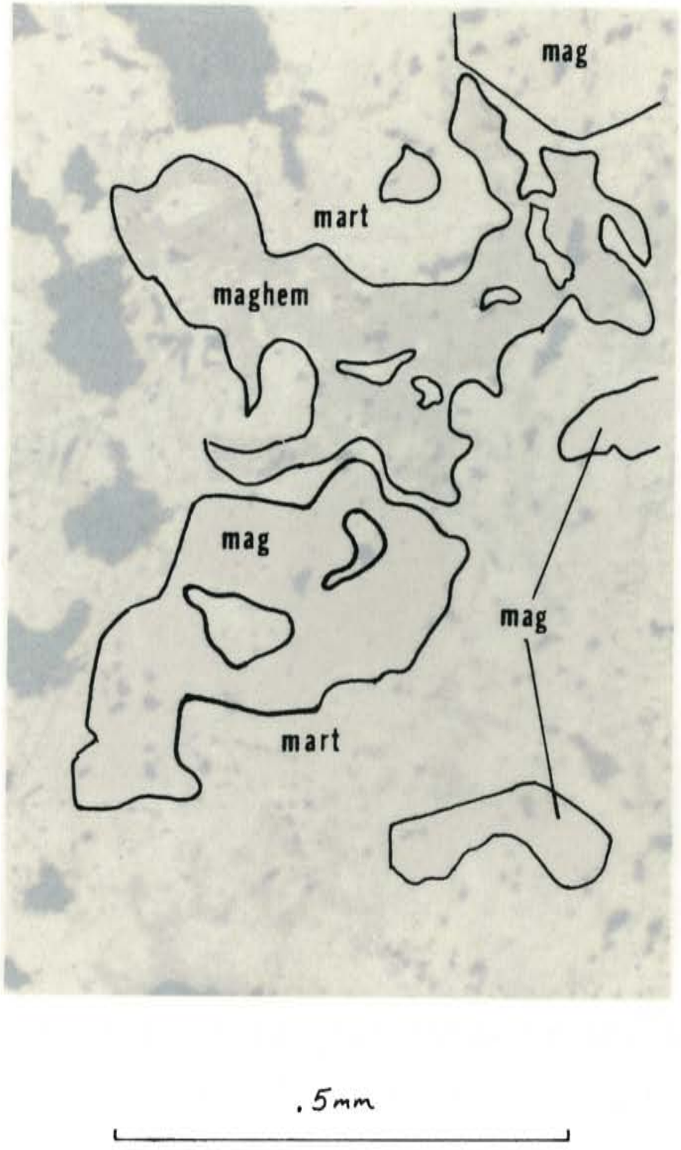


Plate 19. Euhedral to subhedral crystals of magnetite showing extensive martitization. Intergranular material consists of hematite and maghemite. Reflected light.

1. sandstone has been the ore host. Here octahedral magnetite can often be seen replacing quartz grains (Plate 20).

2. open space filling in gypsum or limestone results in a vuggy texture.

3. replacement of early formed sulfides, particularly pyrite, has occurred.

Other minerals present in the ore include maghemite and ilmenite.

Mineral Textures

Magnetite is the most abundant and earliest formed oxide mineral often displaying lamellar intergrowths of ilmenite which may be described as a trellis-type microtexture (Plate 21). These intergrowths are often difficult to distinguish from martite development, especially where martitization has been minor. Martite is usually best developed along crystal borders, rimming the magnetite crystals and becoming more sparse towards its center. Finer, needle shaped lamellae of ilmenite are generally more evenly distributed throughout the crystal.

Pseudomorphs of hematite after early formed pyrite can be seen in a few sections where concentric, alternating

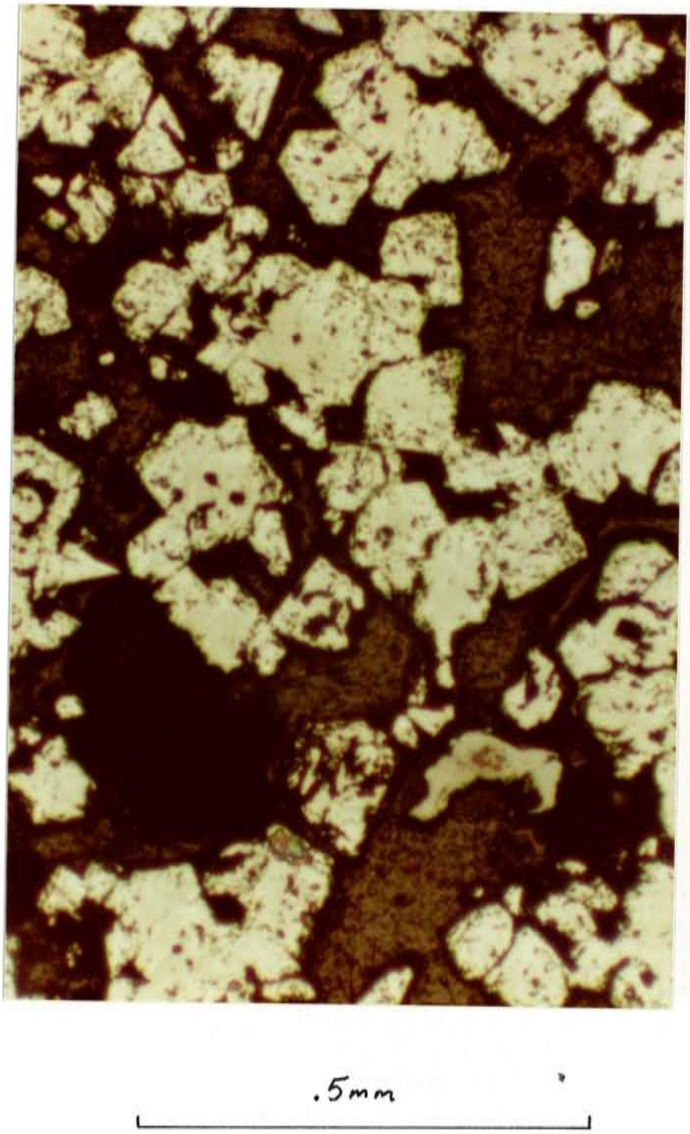


Plate 20. Photomicrograph showing octahedral magnetite replacing sandstone. Reflected light.

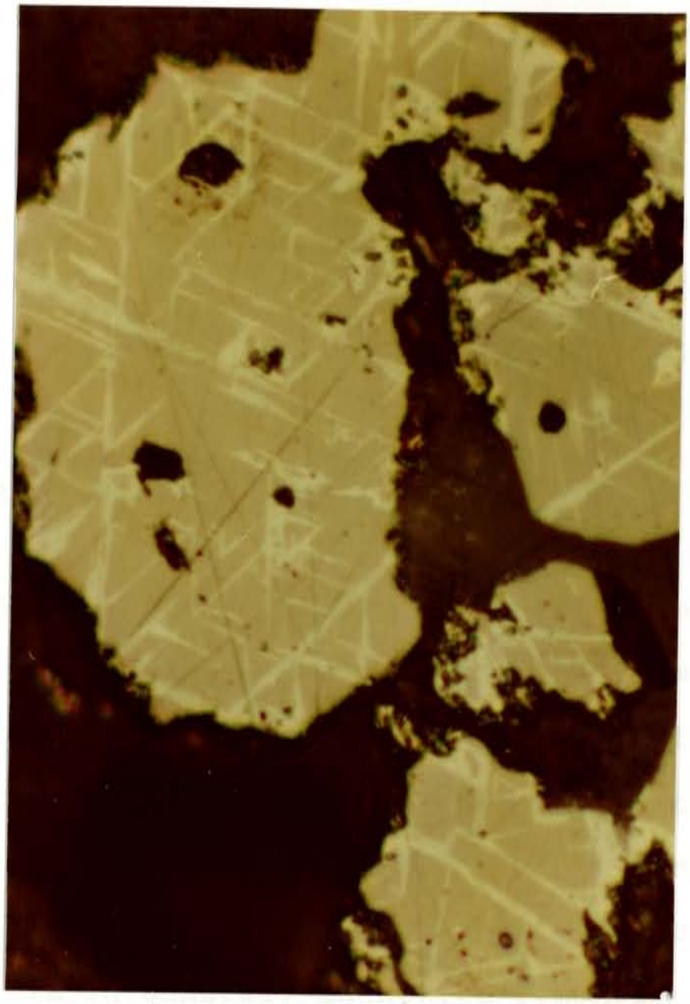


Plate 21. Photomicrograph showing trellis-type microtexture of ilmenite lamellae in magnetite. Reflected light.

bands of maghemite and hematite rim a hematite core. These pseudomorphs can also be seen in hand specimen where perfect cubes of hematite show well developed striations, typical of pyrite cubes (Plate 22). Sample JCS-PY was collected near an ore-gypsum contact and contains nearly fifteen percent pyrite occuring interstitially among martitized magnetite crystals. Nogueira (1971) suggests that iron rich solutions in contact with gypsum produced the following reaction:

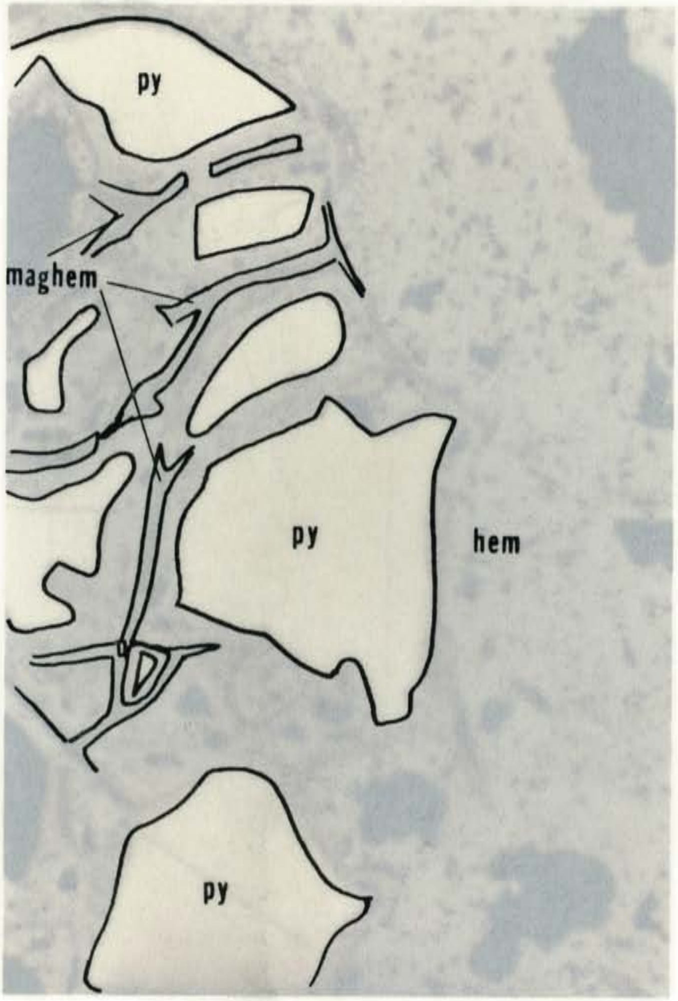
$$2\ CaSO_4.2\ H_2O + 2\ H + Fe = FeS_2 + 2\ Ca + 7/2\ O_2 + 3\ H_2O$$

resulting in the development of pyrite. Maghemite can be seen replacing this pyrite along crystal boundries as well as along microfractures within pyrite crystals (Plate 23). A few thin sections show maghemite as an interstitial mineral among magnetite crystals which may represent total replacement of pyrite (Plate 24). The paragenetic sequence of ore minerals is in general, magnetite-ilmenite-pyrite-maghemite-hematite.

Regional and Local Structure

Jones Camp is located on the southwestern limb of a broad N-NW trending syncline and is immediately underlain by Permian rocks of the Yeso, Glorieta and San Andres Formations. To the southwest, the N-NW trending exposures become progressively older until the PC basement rocks are

Plate 22. Pseudomorphs of hematite after early formed pyrite. Close inspection reveals striations on these cubes; typical of pyrite. Crystals measure 2-3 mm across.



.5mm

Plate 23. Pyrite being replaced by hematite and maghemite. Sample collected at the contact between massive ore and gypsum. Reflected light.

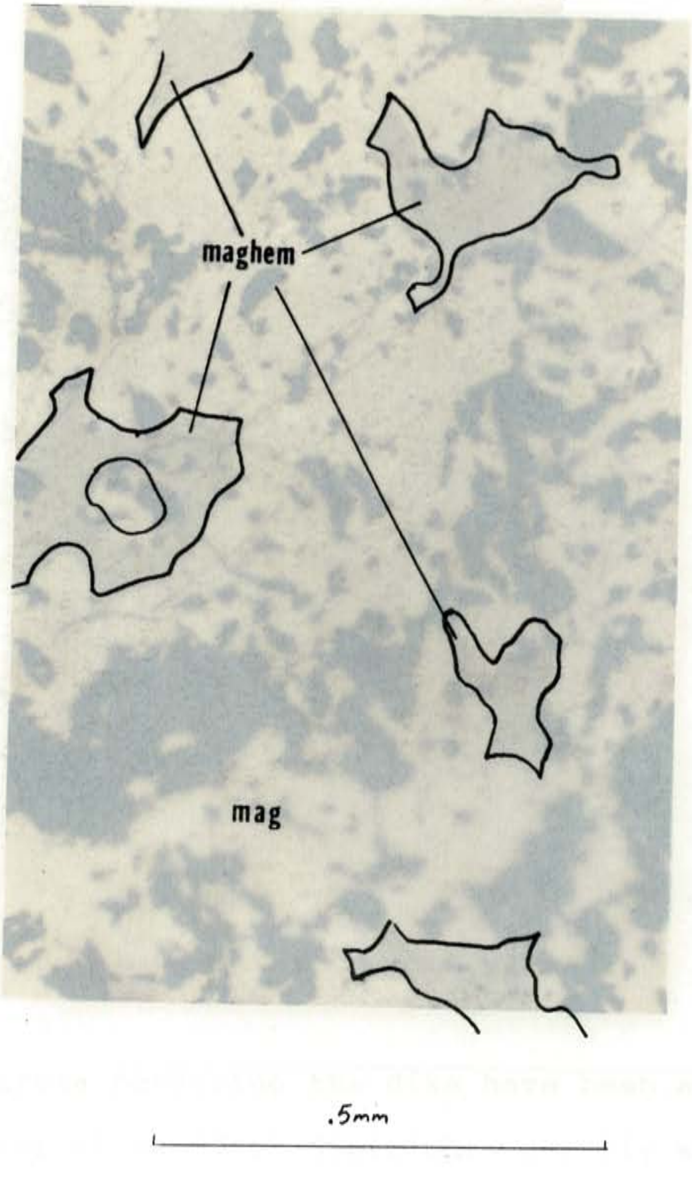


Plate 24. Interstitial maghemite in magnetite. Reflected light.

exposed at the foot of the Oscura escarpment. This west-facing scarp is separated from Quaternary sediments of the Jornado del Muerto basin by a major north-south trending vertical fault. Aside from a mild warping of the stratigraphy of this region, there is a gentle regional dip to the east and southeast.

Locally, only Permian rocks of the Yeso, Glorieta and lower San Andres Formations are exposed. The prevailing structural feature of the study area is that of a small, east-west trending anticline which overlies a monzonitic intrusive, the " Jones Camp Dike " (Figure 7). The dike's exposure can be traced for nearly ten miles until it disappears to the west beneath the northern Oscura Anticline and to the east beneath younger Permian strata. Geophysical data combined with gentle anticlinal warping indicate that the dike extends for at least two miles beyond the easternmost exposure.

Permian strata bordering the dike have been sharply upturned; however this effect diminishes greatly within one hundred feet from the dike's boundaries where the beds tilt gently, forming the gentle anticlinal structure previously described. The topographic expression of the dike in the Jones Camp area is that of a prominent east-west ridge (formed of dike rock) which crops out in the core of the irregularly eroded anticline. Permian sediments form erosional scarps to either side of the dike. These cuestas are separated from the dike ridge by a sharply incised

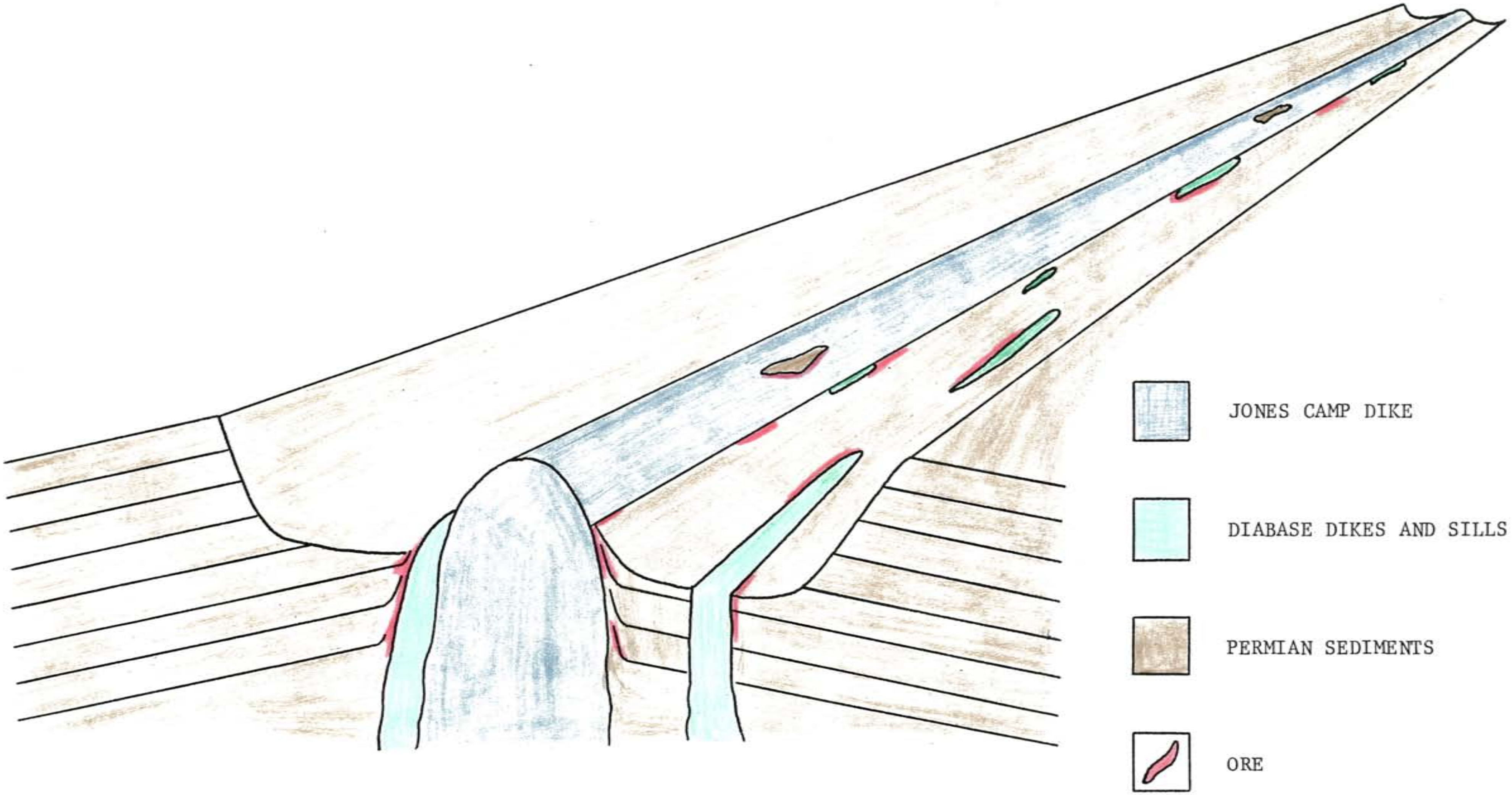


Figure 7. Idealized structure of the Jones Camp study area.

valley which formed in the soft Permian strata.

Numerous diabase dikes and sills occur sporadically at or near the border of the central monzonitic dike and post-date its intrusion. Their length can be traced for up to one mile, especially to the south of the central dike where they cross-cut the Permian rocks.

Pods of magnetite-hematite occur adjacent to the Jones Camp Dike and are often intimately associated with the diabase dikes and sills.

GEOCHEMISTRY

Jones Camp Dike

Purpose and Scope

A geochemical investigation of the Jones Camp Dike was undertaken to see how the major oxide content varies across the dike; to see if these trends across the dike are in agreement with modal trends and to see if these trends along with modal trends can be used in the interpretation of the dike's origin.

Analytical Method

Samples collected for petrographic study were also prepared for major element analysis. Analyses were performed with a Rigaku DMAX Spectrometer.

Sample Preparation

Dike samples were crushed and ground to a fine powder. Pressed powder specimen discs were prepared as described by Hutchinson (1974) in duplicate so that forty-two major element analyses were performed. Combined water and carbon dioxide concentration was determined by the Loss-on-

Ignition method.

Analytical Results

Tables 1 and 2 show the results of major element analyses for twenty-one samples (duplicates were averaged) along with their normative concentrations. These data are plotted (Figures 8a,b and 9a,b) so that variations across the dike in each detailed study area can be correlated easily with modal trends.

Geochemical Trends

The following major oxide trends can be observed across the dike:

1. the behavior of Fe_2O_3, TiO_2 and to some degree MnO is erratic and unpredictable, lacking any trend across the dike.

2. Fe_2O_3, TiO_2 and to some degree MnO are closely tied together as they show the same fluctuations across the dike.

3. the Section 24 detailed study area seems to lack any trends in major elements across the dike whereas the Section 18 detailed area

	1	2	3a	3b	3c	3e	3f	3h
SiO_2	56.82	50.65	63.17	61.77	49.58	58.73	51.46	54.34
TiO_2	.94	1.53	.76	.91	1.88	1.17	1.92	1.68
Al_2O_3	17.41	16.61	16.71	17.03	16.22	17.98	17.00	16.56
Fe_2O_3	3.73	10.21	3.37	3.76	12.47	5.51	9.36	5.69
MnO	.05	.08	.04	.06	.09	.06	.08	.09
MgO	3.07	5.70	1.65	2.79	5.82	2.39	4.89	4.57
CaO	5.07	8.61	2.42	2.46	8.25	3.01	6.33	6.16
Na_2O	7.91	4.08	9.78	8.65	4.84	7.87	5.53	6.42
K_2O	1.56	.95	.95	1.45	.71	2.44	2.07	1.84
L.O.I.	1.54	2.18	.65	1.13	1.70	.85	.85	1.65
TOTAL	98.10	100.60	99.50	100.01	101.56	100.01	99.49	99.35
Q	-	.84	-	-	-	-	-	-
Or	9.41	5.58	5.64	8.57	4.13	14.43	12.30	10.99
Ab	56.37	34.34	78.64	73.23	40.35	61.34	42.87	48.99
An	7.51	24.04	-	3.30	20.08	6.59	15.54	11.16
Ne	6.45	-	1.30	-	-	2.87	2.27	3.21
Di	5.34	4.74	3.40	2.08	4.98	1.54	3.36	4.99
Wo	6.18	5.49	3.93	2.41	5.76	1.79	3.89	5.77
Hy	-	9.38	-	-	-	-	-	-
Ol	1.72	-	.52	3.41	.52	3.09	6.23	4.57
Hm	3.81	10.14	2.73	3.76	12.32	5.51	9.41	5.75
Pf	1.63	-	1.30	.24	.80	1.99	3.29	2.89
Tn	-	3.73	-	1.88	3.39	-	-	-
Ac	-	-	1.90	-	-	-	-	-

Table 1. Major oxide concentrations across the Jones Camp Dike in the section 24 detailed study area. Normative calculations also presented.

	1a	1b	2	3	4	5	6	7	8	10	11	12	13
SiO_2	46.03	47.93	46.65	50.99	50.11	53.17	55.53	52.53	58.53	57.82	53.41	51.80	47.75
TiO_2	1.11	1.20	1.20	1.44	1.51	1.20	1.18	1.48	1.14	1.24	1.18	1.47	1.55
Al_2O_3	16.76	16.30	17.58	15.17	17.20	16.78	17.57	16.48	18.22	18.04	17.44	16.64	16.48
Fe_2O_3	5.47	5.99	4.47	9.70	8.69	3.76	4.52	8.21	5.27	5.90	3.88	5.94	4.69
MnO	.04	.05	.05	.08	.07	.05	.08	.09	.06	.06	.05	.06	.06
MgO	7.57	7.55	5.81	5.75	6.05	4.15	4.06	4.50	2.60	2.75	3.48	4.59	4.10
CaO	12.18	10.92	13.27	7.58	8.66	6.40	5.31	6.71	3.12	2.91	6.90	7.12	13.17
Na_2O	3.79	4.51	4.30	4.74	3.94	6.18	6.94	5.44	8.42	8.60	6.87	6.07	5.78
K_2O	1.04	.08	.37	1.03	.97	1.41	1.46	1.78	1.94	1.88	1.79	2.05	-
L.O.I.	4.37	3.62	4.52	.96	1.60	1.28	1.93	1.29	.88	.73	2.49	2.10	3.31
TOTAL	98.36	98.15	98.22	97.44	98.80	94.38	98.58	98.87	100.18	99.93	97.49	97.84	96.59
Or	6.25	.48	2.23	6.25	5.81	8.83	8.76	10.66	11.46	11.13	10.86	12.39	-
Ab	17.51	32.20	21.34	41.18	33.78	51.54	55.10	46.26	61.98	61.36	44.03	39.48	29.55
An	26.19	24.47	28.12	17.61	26.72	14.77	12.75	16.38	6.13	4.97	11.66	12.27	12.74
Ne	8.18	3.64	8.50	-	-	2.10	2.45	.20	5.00	6.25	8.48	7.08	11.41
Di	11.34	9.53	12.55	5.72	4.14	5.21	3.55	4.38	1.94	1.87	6.96	6.72	10.57
Wo	13.12	11.03	14.52	6.62	4.79	6.03	4.10	5.06	2.24	2.16	8.05	7.78	17.72
Hy	-	-	-	5.86	9.36	-	-	-	-	-	-	-	-
Ol	5.49	6.76	1.52	2.19	1.24	4.02	4.71	4.89	3.18	3.50	1.36	3.48	-
Hm	5.56	6.11	4.55	9.96	8.80	3.98	4.59	8.32	5.27	5.91	3.98	6.08	4.85
Pf	1.92	2.08	2.08	-	-	2.16	2.04	2.55	1.94	2.11	2.06	2.56	2.73
Tn	-	-	-	3.63	3.75	-	-	-	-	-	-	-	-

Table 2. Major oxide concentrations across the Jones Camp Dike in the section 18 detailed study area. Normative calculations also presented.

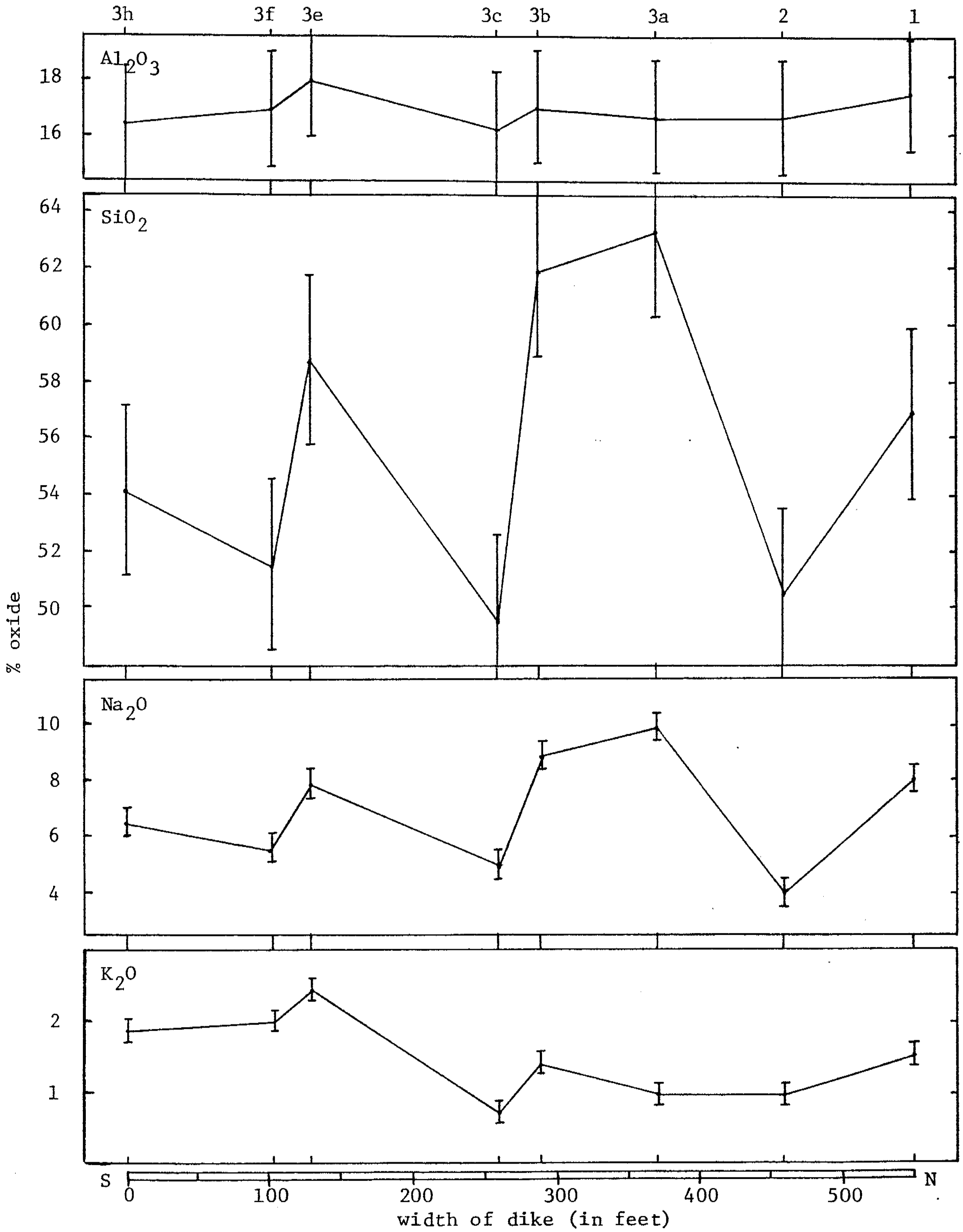


Figure 8a. Variation in major oxide concentration across the Jones Camp Dike in the section 24 detailed study area. Vertical bars represent range of analytical error.

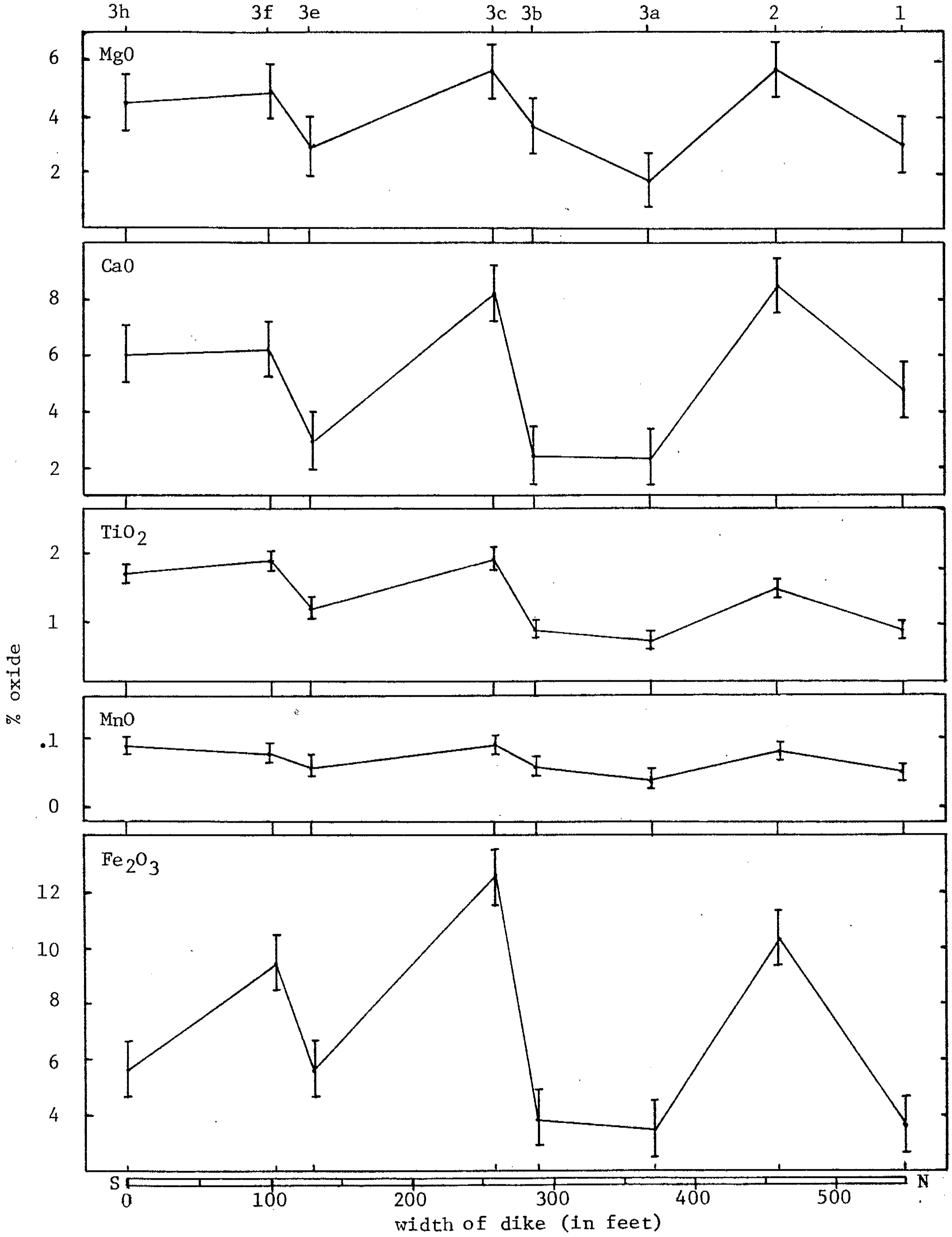


Figure 8b. Variation in major oxide concentration across the Jones Camp Dike in the section 24 detailed study area. Vertical bars represent range of analytical error.

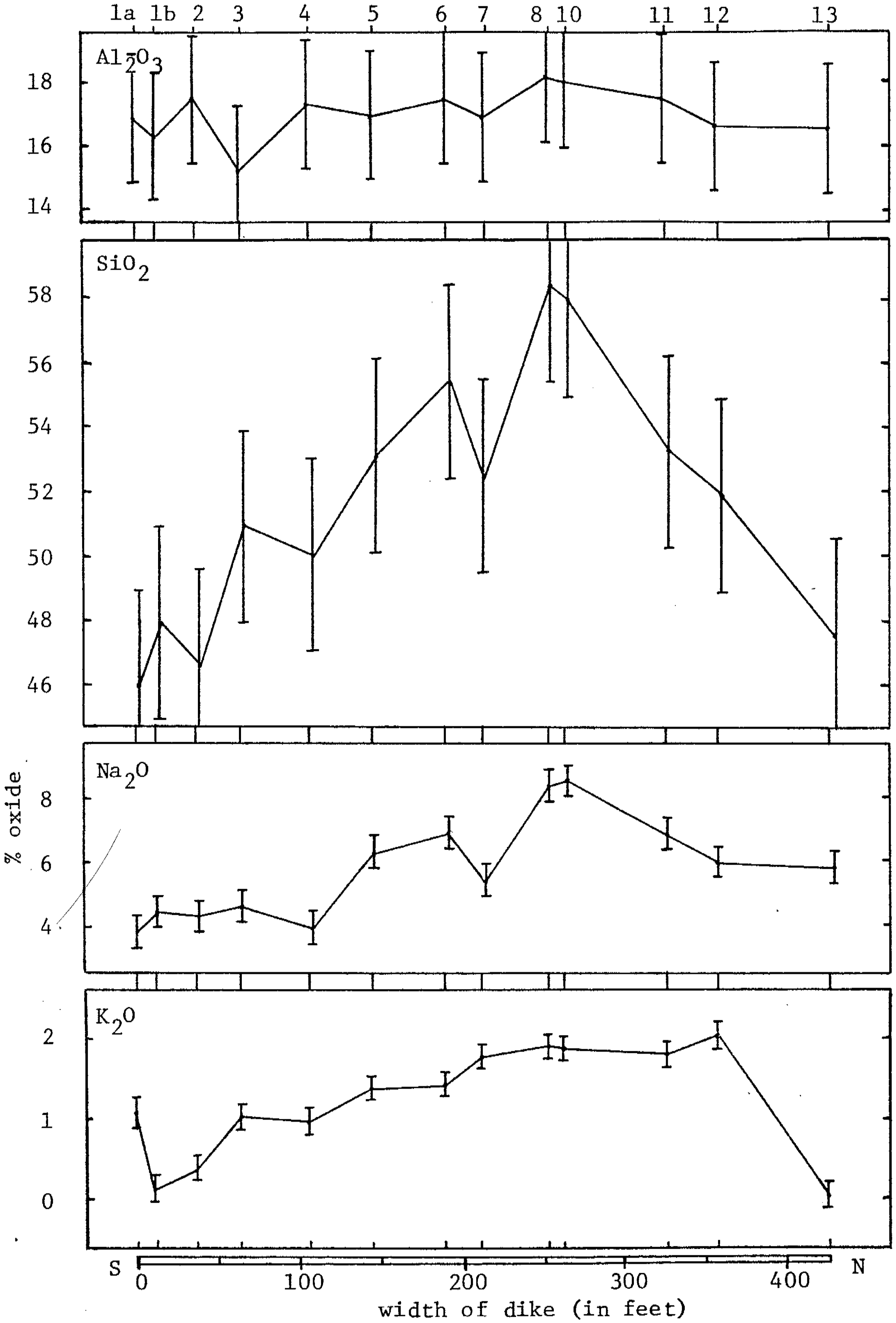


Figure 9a. Variation in major oxide concentration across the Jones Camp Dike in the section 18 detailed study area. Vertical bars represent range of analytical error.

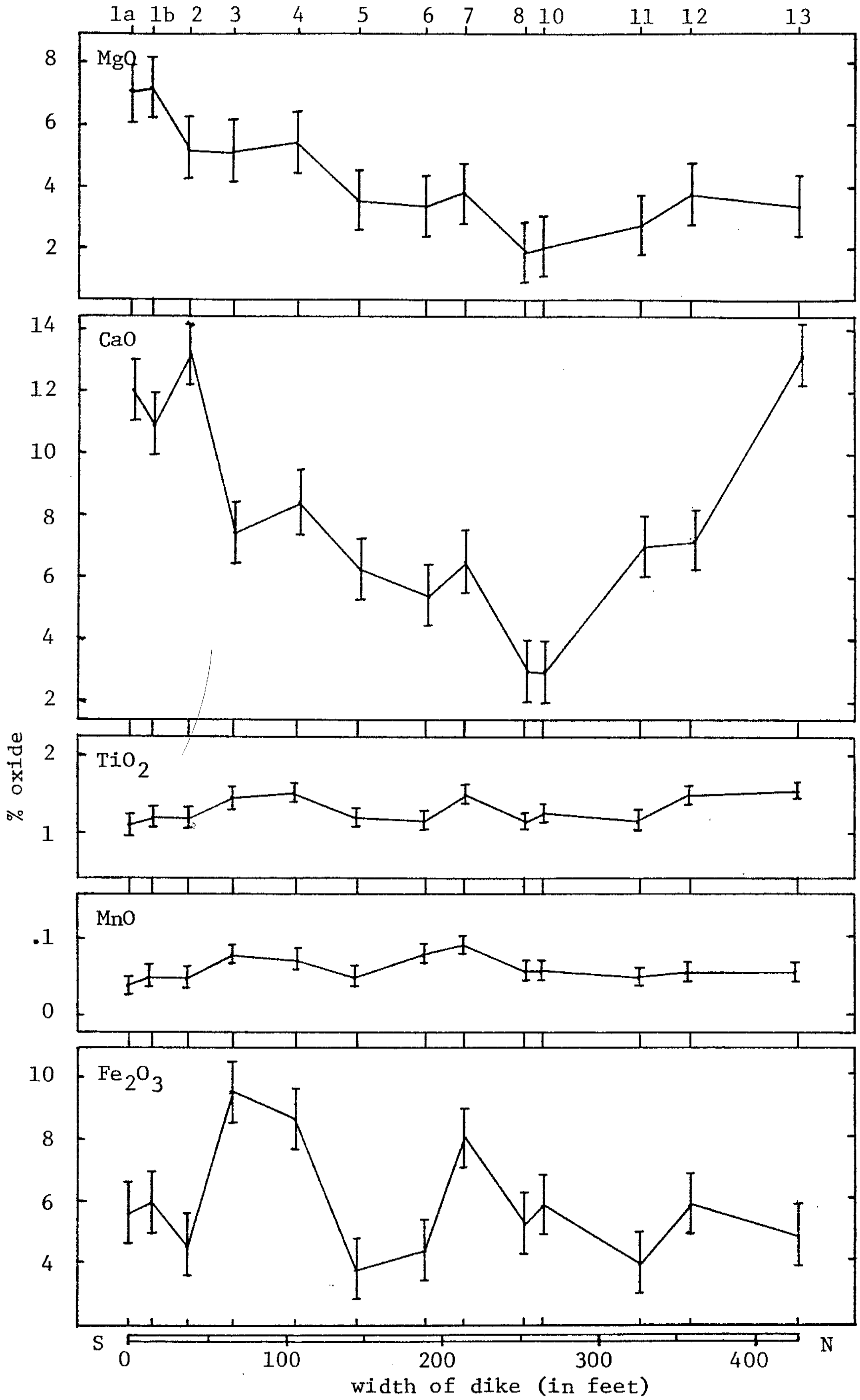


Figure 9b. Variation in major oxide concentration across the Jones Camp Dike in the section 18 detailed study area. Vertical bars represent range of analytical error.

shows a distinct trend which correlates well with modal trends. CaO and MgO show a general increase towards the dike's border while SiO_2, K_2O and Na_2O show a general decrease.

4. Fe_2O_3, TiO_2 and MnO follow the same fluctuations as CaO and MgO, particularly in the Section 24 samples.

Variation in major oxides across the dike show some broad trends in the section 18 detailed study area which compare favorably with modal trends. In particular, the decrease in SiO_2, Na_2O and K_2O and increase in CaO and MgO toward the dike's margins resembles a zoned dike in which a felsic core grades into a more mafic margin.

Any model proposed for the origin of this zonation must consider some inconsistencies in the data:

1. a lack of any chemical trends across the Jones Camp Dike in the section 24 study area.

2. a lack of trends exhibited by TiO_2 and Fe_2O_3.

3. the numerous perturbations in the chemical trends across the dike which deviate from the much broader trends.

Variation Diagrams

Silica variation diagrams were plotted for samples collected in both detailed study areas to see if these samples fall into a chemically coherent group. SiO_2 is plotted against CaO, MgO, TiO_2, Na2O + K2O, and Fe2O3; the results are plotted on figure 10.

All elements with the exception of Fe_{2O3} show a fairly tight geochemical coherence (i.e. they can be related to some process of fractionation); particularly among the high-silica samples. While Fe_2O_3 shows appreciable scatter, it shows a vague trend which is consistent with trends exhibited by CaO, MgO and TiO_2.

A marked departure from these trends (particularly among the section 18 rocks) is observed in the low silica border rocks of the Jones Camp Dike and is worthy of note:

1. border rocks of the section 18 study area show a marked depletion in Fe_2O_3 and TiO_2.

2. CaO shows an enrichment in the border rocks of the section 18 study area.

Indicated Models For the Origin of the Jones Camp Dike

Based on field relationships, petrographic studies and geochemical data, three models are considered for the origin

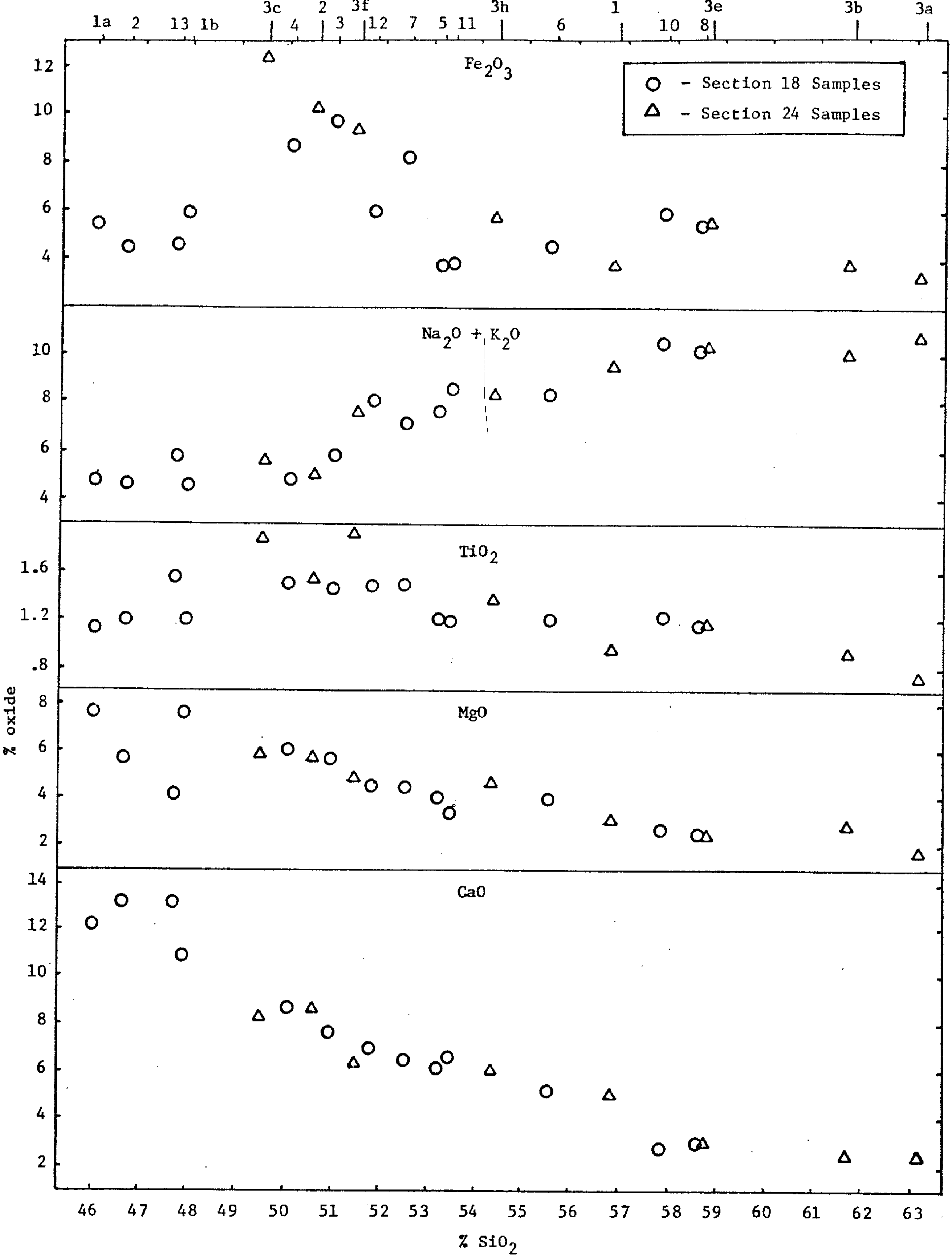


Figure 10. Silica variation diagrams of the section 24 and section 18 rocks from the Jones Camp Dike.

of the Jones Camp Dike:

1. The chemical and mineralogical zonation is a result of differentiation in situ.
2. The chemical and minerological trends across the dike can be attributed to secondary processes.
3. The Jones Camp Dike is a composite dike formed by multiple intrusions.

Model 1: Differention In Situ

Differentiation of a still, crystallizing magma body by the process of diffusion and perhaps convection as described by Harker (1965) is the least plausible explanation for the origin of the Jones Camp Dike. Under this scheme, the following processes would take place:

1. an intruded magma cooling by conduction against the cooler, surrounding country rocks will develop a temperature gradient such that marginal-magma is at a lower temperature than core-magma.
2. when the temperature of the border-magma cools

to a point where crystallization can begin, early forming minerals (olivine, orthopyroxene and anorthitic plagioclase) begin to crystallize.

3. a depletion of Mg, Fe and Ca, the basic constituents of early formed crystals in a once homogeneous magma, will cause their diffusion towards the dike's border such that compositional homogeneity of the magma is maintained. Simultaneously, the enrichment of Si, Na, K and volatile constituents in the border will cause their being diffused in the direction of the dike's interior.

This mechanism for the development of a zoned dike will understandably only be applicable for large, slowly crystallizing magma bodies.

This model is unlikely in view of the chemical trends observed across the dike. The process of fractional crystallization in situ should result in an igneous body which displays a completely gradational zoning from a mafic border facies to a more felsic core.

While silica variation diagrams indicate a chemically coherent group of rocks which is best related to some process of fractional crystallization, there seems to be little indication that a once homogeneous magma differentiated in situ. Chemical variation across the dike does not display a smooth change from core to edge nor is this trend symmetrically developed; particularly in the section 24 study area. Furthermore, Fe_2O_3 and TiO_2 lack any trends across the dike in either study area. This is not consistent with an in situ model of differentiation.

Model 2: Secondary Processes

The depth of penetration of intense hydrothermal alteration in the Jones Camp Dike is represented by the mottled border facies, first named and described by Nogueira (1971). Whereas an isochemical status for the interior of the dike has probably been maintained since its emplacement (as indicated by the general lack of intense alteration) this has probably not been the case for the border rocks.

Alteration of the dike's interior can best be explained by deuteric effects, an isochemical process in which late magmatic juices alter early formed minerals. According to Moorehouse (1959), deuteric alteration is recognized by the following replacements:

1. ferromagnesian minerals, principally pyroxene, alter to fibrous aggregates of hornblende (uralite), chlorite and carbonates.

2. plagioclase typically alters to epidote group

minerals (saussurite), sericite, carbonates and albite.

3. titaniferous magnetite is often surrounded by leucoxene (similar to sphene) or alters to lamellar intergrowths of leucoxene.

These secondary replacements are typical of inner-dike rocks.

Peripheral alteration of the dike is typically more massive with large aggregates of tremolite and actinolite replacing minerals indiscriminantly. This suggests that the border facies has undergone flooding by hydrothermal solutions. Under these conditions, an exchange of ions is inevitable. Nogueira (1971) suggests that a depletion of Fe, Ti and Ca and an addition of Si, Na and Al in the border facies rocks had occurred based on major element trends which he projected from the dikes relatively unaltered core to the border rocks. The present study suggests that a depletion in iron and titanium and an enrichment in calcium in the highly altered border rocks had taken place.

The Section 18 major element study (particularly SiO_2, Na_2O, K_2O, MgO and CaO) displays trends which are in agreement with modal trends; the increase in concentration of CaO and MgO towards the dike's margin is accompanied by a decrease in SiO_2, K_2O and Na_2O. Numerous perturbations in this broad trend exist however which cannot be explained by simple secondary modification. While border facies rocks seem to have been modified by secondary processes, the bulk of the inner dike rocks show geochemical coherence which is best explained by some fractionation process.

Based on these fundamental observations, it is unlikely that the mineralogic and chemical trends across the dike (with the exception of the border rocks) are of a secondary nature; rather they are most likely a feature inherent to the original magma.

Model 3: Composite Intrusive

Nogueira (1971) considers the Jones Camp Dike to be of a composite nature; the character of the dike can be attributed to multiple episodes of intrusion under a normal differentiation trend.

There is no strong evidence in the field which would suggest that the Jones Camp Dike is typical of composite dikes described in the literature (i.e. internal chilled margins, zenoliths of earlier intruded phases within later pulses of magma or distinct chemical zoning from the core to the margin of the dike)(Harker, 1965). However the degree to which the properties which typify most composite dikes are developed is dependent on the time interval between successive pulses. Intrusions closely spaced in time where the core of the previous intrusion is still molten would fail to yield a sharp chilled contact. In this case, an assimilated margin between the two facies would likely develop resulting in a diffuse, poorly defined and irregular contact.

While lateral continuity of the four composite facies which Nogueira deliniated in the dike is not substantiated by a detailed study of two other dike cross sections, distinct mineralogic zones (as represented by the variations in major minerals across the dike) do exist throughout the dike which likely represent separate intrusive episodes.

Silica variation diagrams suggest that the various mineralogic zones represented throughout the dike can be related to a single fractionating source. A composite model can best explain the numerous perturbations in major oxide content across the dike in which successive intrusions, closely spaced in time, would result in cross-cutting relationships with earlier intrusions such that contacts are poorly defined and difficult to recognize in the field. This would account for the lack in smooth compositional variation across the dike yet allow a broader trend (from a felsic core to a more mafic border) to exist.

Diabase

No major oxide determinations were made on the diabase dikes and sills in the field area; however Nogueira (1971) ran a single analysis on the diabase from his detailed study area; the results of this analysis are as follows:

	%
SiO_2	55.56
TiO_2	1.97
Al_2O_3	13.47
Fe_2O_3	8.11
MgO	6.66
CaO	7.19
Na_2O	5.26
K_2O	0.96

With the exception of the anomolously low Al_2O_3, major oxide concentrations are very similar to the dioritic composition of the Jones Camp Dike. A lack of distinction between these two intrusive types is also supported by field and petrographic observations.

A more detailed investigation of the diabase intrusives is necessary so that their relationship with the Jones Camp Dike can be better understood.

Ore Geochemistry

Purpose and Scope

Geochemical investigation of the Jones Camp Ore was undertaken to see if trace elements could be used to better understand the origin of the mineralization; its source, its mode of transport and the conditions of ore deposition. It is also hoped that this study will provide information which will be helpful in the approach to mining and milling practices.

Controls For the Distribution of Trace Elements

Numerous studies have been undertaken in an attempt to understand the origin of magnetite deposits based on their trace element geochemistry. Hegemann and Albrecht (1954) and Frietsch (1970) compiled large amounts of data from magnetite deposits worldwide. They categorized these deposits based primarily on field and petrographic observations, relying strongly on the individual workers interpretation. Trace element data was then correlated with these observations to see if any trends exist.

Geochemical Modelling of Ore Deposits

In modelling the origin of an ore deposit or a group of rocks based on their trace element content, certain assumptions are made. Ideally, the uniform behavior of individual elements or groups of elements under similar geologic processes should yield uniform and predictable results. In the same regard, trace element data from ore deposits (or groups of rocks) which may be related to a single model, should show trends which are consistent with that model. Trace element data from the Jones Camp ore deposit should then correlate with similar data from deposits in which the same processes were operable.

Trace Element Behavior Under Various Geologic Processes: Goldschmidt´s Rules.

There is abundant experimental data pertaining to the behavior of trace elements in crystallizing magmatic systems. However few studies have been carried out on the behavior of trace elements between coexisting immiscible fluids (i.e. melts or hydrous phases). The few reported (Graf, 1977) generally include only rare earth studies.

Crystallizing Magmas

The degree to which a trace element substitutes into a given mineral is a function of temperature, pressure and the physical and chemical properties of the mineral and trace elements involved. Goldschmidt (1937) first suggested that the relative abundance of various trace elements in any mineral is controlled by the ionic radius and charge of the elements involved. He formulated three rules for the distribution of trace elements among minerals during magmatic crystallization:

1. If two ions have the same charge, they will enter a crystallizing mineral with equal ease.

2. If two ions have similar radii and equal charge, the smaller ion will be preferentially selected to substitute in the earlier formed minerals.

3. If two ions have similar radii but different charges, the ion with the greater charge will be preferentially incorporated into the earlier formed crystals.

These rules explain the distribution of some trace elements in crystallizing magmas. However numerous exceptions to these rules have made it necessary to modify or add to them. Ringwood (1955) suggested that the covalent nature of many silicate minerals (Goldschmidt's rules were based on ionic bonds only) made it necessary to account for differences in bond strengths so that a fourth rule was added:

4. If two elements have similar radii and the same charge, the ion with the lower electronegativity will be preferentially concentrated in the earlier formed minerals (because it forms a stronger ionic bond).

Burns (1970) further modified these rules which could not explain the behavior of transition elements as observed in many igneous rocks. Based on crystal field theory he was able to explain many of the inconsistencies of transition elements; this led to the fifth important rule:

5. If two ions have the same electronegativity and can substitute for one another, the ion with the greater total bonding energy will enter a lattice site more readily (Nockolds, 1966).

Table 3 summarizes the ionic charge, ionic radius, electronegativity and total bond energy for the elements under consideration in this paper.

Fluid Systems

In the approach to understanding trace element behavior in fluid systems, numerous types of systems may be considered, some of which are:

	Ionic Charge	Ionic Radius (Å)	Electro-negativity	Total Bonding Energy
Cr	+3	.63	1.6	323
Fe	+3	.64	1.8	246
Mg	+2	.66	1.2	206
Ti	+4	.68	1.6	391
Ni	+2	.69	1.8	175
Co	+2	.72	1.7	166
Cu	+2	.72	2.0	165
Zn	+2	.74	1.5	174
V	+3	.74	1.4	311
Fe	+2	.75	1.65	159
Mn	+2	.80	1.4	154
Ca	+2	.99	1.0	220

Table 3. Ionic charge, ionic radius, electronegativity and total bond energy for several elements. All values from Taylor (1965) except for bond energies (from Nockolds, 1966).

1. coexisting immiscible melts in a magmatic system.

2. hydrous fluids whose interaction has been limited to the crystallizing magma from which the fluids were generated.

3. hydrous fluids whose interaction with host rocks has been varied and complex.

The application of trace elements to fluid systems is limited. The problem with using trace elements as tracers in hydrothermal or fluid systems is largely the result of a lack of experimental or theoretical data. Natural systems can rarely be duplicated in the laboratory (particularly hydrothermal systems) due to their complex nature; some of these complexities are:

1. the chemistry of hydrothermal solutions varies greatly with temperature, pressure, source and host rock chemistry.

2. the open nature of most hydrothermal systems generally results in unpredictable variations in temperature and pressure.

3. hydrothermal systems (particularly low

temperature systems) have few distinctive characteristics making interpretations of their history difficult.

While these systems are poorly understood, trace elements are of some use in the interpretation of certain types of hydrothermally related deposits since it is recognized that these deposits exhibit trends in their trace element distribution which are distinct.

Thus, these systems might be better understood by looking at the available quantitative trace element data from numerous hydrothermally related deposits.

The Behavior of Transition Elements

Transition elements are strongly partitioned into early- formed magnetites so that their values tend to be higher in magnetite belonging to early stages of fractional crystallization. Wager and Mitchell (1951) show this trend to be well developed in rocks of the Skaergaard complex. The earlier formed more mafic layers of the intrusive are high in these elements. A decrease upward occurs within each layered series as the rocks become more felsic in composition.

Chromium substitutes readily for Fe^{3+} having a similar ionic radius, a lower electronegativity and a higher total bond energy.

Titanium, at high temperatures, forms a solid solution with ulvo-spinel (Fe_2TiO_4). It substitutes easily for Fe^{2+} or Fe^{3+} since its ionic radius falls between them, has a similar or lower electronegativity, a lower ionization potential and a higher relative total bonding energy.

Nickel is also most commonly found in early-formed magnetite, substituting for Fe2+. It has a smaller ionic radius and a lower ionization potential.

Cobalt substitutes for either Fe2+ or Fe^{3+} although preferentially replaces Fe^{2+}, having a smaller ionic radius, and a similar electronegativity, total bond energy and ionization potential.

Vanadium substitutes most often for Fe^{3+} having a lower electronegativity, a lower ionization potential and a considerably higher total bond energy.

The Behavior of Mg, Ca, Mn, Cu, and Zn

The behavior of Mg, Ca, Mn, Cu, and Zn in a crystallizing magma body is fairly well known. All of these elements show some degree of substitution in the magnetite structure depending on the elements available and the temperature of magnetite crystallization. Bivalent Ca, Mg and Mn are generally incorporated more readily into early-formed magnetite, probably due to the their relatively low electronegativities. Mg2+ is able to form a continuous replacement with Fe2+ in the development of magnesioferrite

($MgFe_2O_4$) (Deer et al., 1962). Magnetite in the Skaergaard complex shows a substantial amount of magnesium entering its lattice in early-formed crystals (Vincent and Phillips, 1954). Although Mn^{2+} has a higher ionic radius than Fe^{2+}, its electronegativity is lower and its total bond energy is nearly equal, making it a fairly good candidate for its substitution. The ionic radius of Ca^{2+} is considerably larger than Fe^{2+} so that it is not normally found in large quantities in magnetite.

Bivalent Cu and Zn behave quite similarly, having nearly the same ionic radius and total bond energy. Because of their relatively large electronegativities, they are more apt to be incorporated into later-formed magnetite. Wager and Mitchell (1951) showed that Cu and Zn substitute in minor amounts in late forming magnetite, as observed at the Skaergaard intrusion.

Phosphorus Content in Magnetite Deposits

Significant quantities of phosphorus have been reported in many of the Kiruna-type and other associated magmatic injection deposits. Kiruna ores of this type are generally referred to as apatite ores. Frietsch (1970) reports a range of .01 to five percent phosphorus for these ores while one to two percent is typical.

Many of the Kiruna-type ores of the Pacific Basin contain appreciable amounts of apatite in the dike like shoots which extend outward from the ore bodies (Park, 1972). Park reports up to thirty percent phosphorus in association with magnetite dikes of the Cemento Melon mine of Chile. Many of the titaniferous magnetite deposits of the Adirondacks contain considerable amounts of apatite as well; Jooste (1949) reports over twenty-two percent apatite in one of the St. Charles magnetite deposits of Quebec. Although no quantitative data is presented, the El Laco magnetite flow contains apatite as one of its principal gangue minerals (Frutos et al, 1975). Hydrothermally related deposits, on the other hand, generally carry only very small quantities of phosphorus, usually less than 0.1 percent (Frietsch, 1970).

Large quantities of phosphorus in magmatic iron deposits are believed to act as a "mobilizer" for the ore magma. The melting temperature of pure magnetite is roughly 1600 degrees C, a temperature far above what is considered to be obtainable under most geologic conditions in the earth´s upper crust. With the addition of fluidizers such as P, Fl and Cl, the melting temperature of magnetite can be depressed significantly, allowing it to be transported in a molten state. Frutos and Oyarzun (1975) suggest that the addition of apatite may lower the crystallization temperature from 1500 degrees C to 1000 degrees C or 800 degrees C allowing magnetite to exist in a volcanic environment. Eggler (1974) supports this view, showing the effect of water on depressing the melting point of magnetite.

There are several examples in the literature in which the intrusive character of an ore is well documented yet few or no fluidizers (particularly phosphorus) are present (Geiger and Odman, 1974). The Old Bed ore body in the Adirondacks as well as the Mertainen ore body of Sweden are good examples. It is possible that during the emplacement of these ores, volatile constituents were carried away from the site of ore deposition (particularly in a shallow environment), leaving little evidence for their presence.

Structural and Chemical Controls For Ore Formation

Structural Controls

The Jones Camp Dike is part of an east-west structural trend which represents the most recent structural imprint on this area. This trend is accentuated by scattered intrusives south and southwest of the present field area which may be congenetic with the Jones Camp Dike and associated intrusives.

The dikes linearity and overall length strongly suggests that it was intruded along a pre-existing fault. Bickford (1980) suggests that while there is a small difference in elevation of strata between the north and south sides of the dike which correlates with normal faults in the area, this evidence is by no means conclusive.

Nogueira (1971) estimated the depth and confining pressure of the dikes emplacement at one to two kilometers and 250 to 500 bars based on regional stratigraphic studies. Sedimentary rocks adjacent to the Jones Camp Dike show abundant evidence of faulting and fracturing.

Chemical Controls

The nature of the mineralized host rock including ore textures and gangue constituents may often indicate the chemical nature of the ore medium and the chemical controls responsible for ore deposition.

Injection-type deposits, in which the ore is carried in a molten state, contain relatively few volatiles so that deposition is probably more strongly controlled by the temperature and structure of the depositional environment. These deposits often contain dike or vein-like features or breccia zones which are indicative of forceful injection or fissure filling. Host rocks are generally of a nonreactive nature showing few signs that deposition was chemically controlled.

In solution transport of iron the reactive nature of the transport medium is generally well supported by the nature of the host rock (usually limestone or limey sediments) and by ore textures which suggest that replacement rather than mechanical filling has been the likely mechanism of ore formation.

Holser and Schneer (1961) present experimental evidence which suggests that HCL-bearing solutions can be important in the solution and transportation of iron. They suggest that HF and H_2CO_3 are probably important as well. The acidic nature of these solutions is supported by two lines of evidence:

1. neutral and alkaline solutions have not been shown to be effective in the solution of iron (Holser and Schneer, 1961).

2. deposition of iron generally takes place when solutions come into contact with calcium carbonate due to an increase in the Ph. This necessitates an acidic ore medium. Eugster and Chou (1979) suggest that magnetite formation takes place by the following reaction:

$$3FeCl_2 + 3CaCO_3 + H_2O = Fe_3O_4 + 3CaCl_2 + 3CO_2 + H_2$$

Ores of this type often exhibit features associated with intense hydrothermal activity.

Analytical Approach and Methodology

Fourteen trace elements were analyzed in nineteen different ore samples, collected from eight localities along the dike. These elements include Co, Mn, Zn, Cr, Ni, Cu, Ti, V, Mg, Ca, Pt, Au, Ag, and P. Accessory magnetite from the Jones Camp Dike and diabase was also analyzed. Bulk samples from each were crushed to minus 100 mesh and the magnetite removed using the process described on page 91. Analyses were carried out by various methods including atomic absorption spectrophotometry, x-ray fluorescence spectrometry, neutron activation analysis and emission spectrography. Their applicability to a particular element is a function of several factors:

1. sensitivity of the instrument.
2. concentration of the element.
3. interferences arising from abnormally high concentrations of other elements (particularly iron).

Emission Spectrography

An ARL Model 2600-1 Spectrographic Analyzer was used in the semiquantitative analysis of all elements under investigation. This instrument was found to have only limited value as a quantitative tool, however the presence of various trace elements and the range over which they occurred was determined. Although the results are not presented, they were helpful in the preparation of further analytical work.

Neutron Activation Analysis (N.A.A.)

Analyses of Ag, Au and Pt-group elements were carried out with a Nuclear Data model 660 gamma-ray photometer in hopes of establishing the concentrations of these three precious metals. This method was chosen because the levels of concentration were below the detectable limit of fire assay techniques.

The particular advantage of N.A.A. is the very low limit of detectablility; in the order of 5 ppb for most elements.

Atomic Absorption Spectrophotometry (A.A.)

A.A. was found to be the best approach for the evaluation of most trace metals in iron ore. The concentrations of ten elements were measured including Co, Mn, Sn, Cr, Ni, Cu, Ti, V, Mg, and Ca. Three different instruments were used in these analyses depending on the units sensitivity and/or availability. A Perkin Elmer model 303 was used for the analysis of Cu, Co and Mn; a Varian Techtron model 1250 was used in the determination of Cr, Ni and Zn and a Varian Techtron model AA6 was used for Ti, V, Mg and Ca analyses.

X-ray Fluorescence Spectrometry (XRF)

XRF was found suitable for the determination of phosphorus. Other methods are considerably more painstaking or inadequate due to the strong interference caused by iron. A Rigaku DMAX Spectrometer was used for the analyses.

Sample Preparation

For all analytical work, ore samples were crushed to -150 mesh. Purified magnetite samples were prepared for use in emission spectrographic and atomic absorption analyses following a procedure outlined by Kisvarsanyi and Proctor (1967). Approximately 20 grams of finely powdered sample was immersed in a beaker of distilled water. A hand magnet wrapped in plastic was used to separate the magnetite from the mixture. This was repeated several times followed by decanting to remove all non-magnetic particles. Non-purified ore samples were used for neutron activation and x-ray fluorescence analysis.

Emission Spectrography

Magnetite powder and iron-matrix standards were well mixed with graphite using a 1:1 ratio with an agate mortar and pestle. Standard concentrations of .1, .01 and .001 percent as well as a blank sample were used for each element analyzed. After each spectrogram was made, care was taken to assure that a consistent developing technique was maintained.

Neutron Activation Analysis

Approximately .5 grams of powder was carefully weighed for each sample and sealed in small polyethelyne vials. Samples were then irradiated at the Sandia Nuclear Facility in Albuquerque, New Mexico.

Atomic Absorption Analysis

Powdered samples were carefully weighed out at 1 gram each and put into solution using various stages of acid digestion. The solution was then brought to volume and run directly on the A.A. along with standards which fell within the optimum working range for each element analyzed. Dilutions were used when concentrations fell above this range.

X-ray Fluorescence

Samples were prepared following the procedure used for the dike samples.

Analytical Results

Table 4 is a compilation of analytical data from atomic absorption and x-ray fluorescence analyses. Precious metal data is included in the appendix.

Trace Element Distribution in the Jones Camp Ore

General Trends

The data presented in Table 4 shows some characteristics which are significant in the interpretation of the mineralization at Jones Camp:

1. Most of the trace elements, with the exception of Zn, Ti, and V, fall within a narrow range of concentration.

2. While there is considerable variation in the abundance of certain trace elements, there still remains a strong similarity in their concentration within a single pod of ore.

3. No consistent trends are observed within a single lense of ore, particularly with respect to the location of the intrusive contact.

SAMPLES	Co	Mn	Zn	Cr	Ni	Cu	Ti	V	Mg(%)	Ca(%)	P(%)
EB3-1	105	150	19	13	35	218	750	1250	nd	nd	.16
EB3-2	180	238	21	10	81	383	1750	2000	nd	nd	.17
EB3-3	93	175	24	8	20	53	300	125	1.08	1.00	.02
EB66N	95	275	53	15	23	138	375	500	nd	nd	.14
EB66C	100	238	36	16	23	255	< 300	< 125	1.45	.30	.15
EB66S	140	475	138	10	20	315	< 300	<<125	3.15	.70	.14
JCS2	98	263	24	8	20	145	< 300	500	.80	2.00	.06
JCS3	133	350	40	16	21	188	<300	325	nd	nd	.13
JCS4	143	600	48	38	19	105	300	<125	3.0	1.1	.14
JCS5	105	475	35	13	13	53	375	< 125	1.50	.45	.15
JCS6	138	613	125	10	20	143	375	125	3.35	1.10	.12
JCSPY	148	438	88	25	29	148	<300	<<125	1.88	1.75	.03
WPS1	108	213	838	16	36	248	1875	5250	nd	nd	.07
WPS2	140	225	280	17	30	185	2500	3200	.63	.79	.12
WPN	108	600	64	19	23	283	<300	<< 125	2.0	.40	0
EB29	135	250	34	8	24	133	<300	250	2.75	3.50	.17
EB30	100	288	34	13	29	240	< 300	450	1.33	1.00	.14
EB47	143	550	64	13	21	210	375	<125	3.0	2.25	.14
EB69	120	213	41	18	50	155	3125	3125	1.04	1.13	.02
Mean	123	349	106	15	28	189	800	950	1.9	1.2	.11
Dike 1	108	1300	78	30	45	63	25500	3200	.25	1.0	nd
Dike 2	110	1225	55	34	54	58	24500	3125	.30	1.0	nd
Diabase	nd	nd	nd	nd	nd	nd	375	nd	nd	nd	nd

Table 4. Trace element concentrations in Jones Camp magnetite ore and accessory magnetite in the Jones Camp Dike and diabase dikes and sills. All values in ppm. except where indicated otherwise.

4. The magnetite separate from the Jones Camp Dike shows an extreme enrichment in Ti (a concentration of nearly ten-fold above the highest ore sample), a two-fold enrichment in Mn above the highest ore samples and significantly higher concentrations of Cr, Ni and V than the mean ore values. Cu and Mg are significantly lower in the dike-magnetite than in the adjoining ore.

Hegemann and Albrecht (1954) compiled the first comprehensive set of data on the trace element geochemistry of numerous types of iron deposits. These data are presented in Figure 11 along with the ranges of trace element contents in the Jones Camp magnetite. No clear comparisons are apparent between the various types of iron ore and the Jones Camp ores based strictly on trace element data. There may be several reasons for this:

1. Certain types of deposits (contact metasomatic for example) exhibit a wide range of values for most elements. This makes it difficult to distinguish deposits which may be distinct in their trace element makeup but fall within these ranges.

2. Much of the data is quite old and the analyses

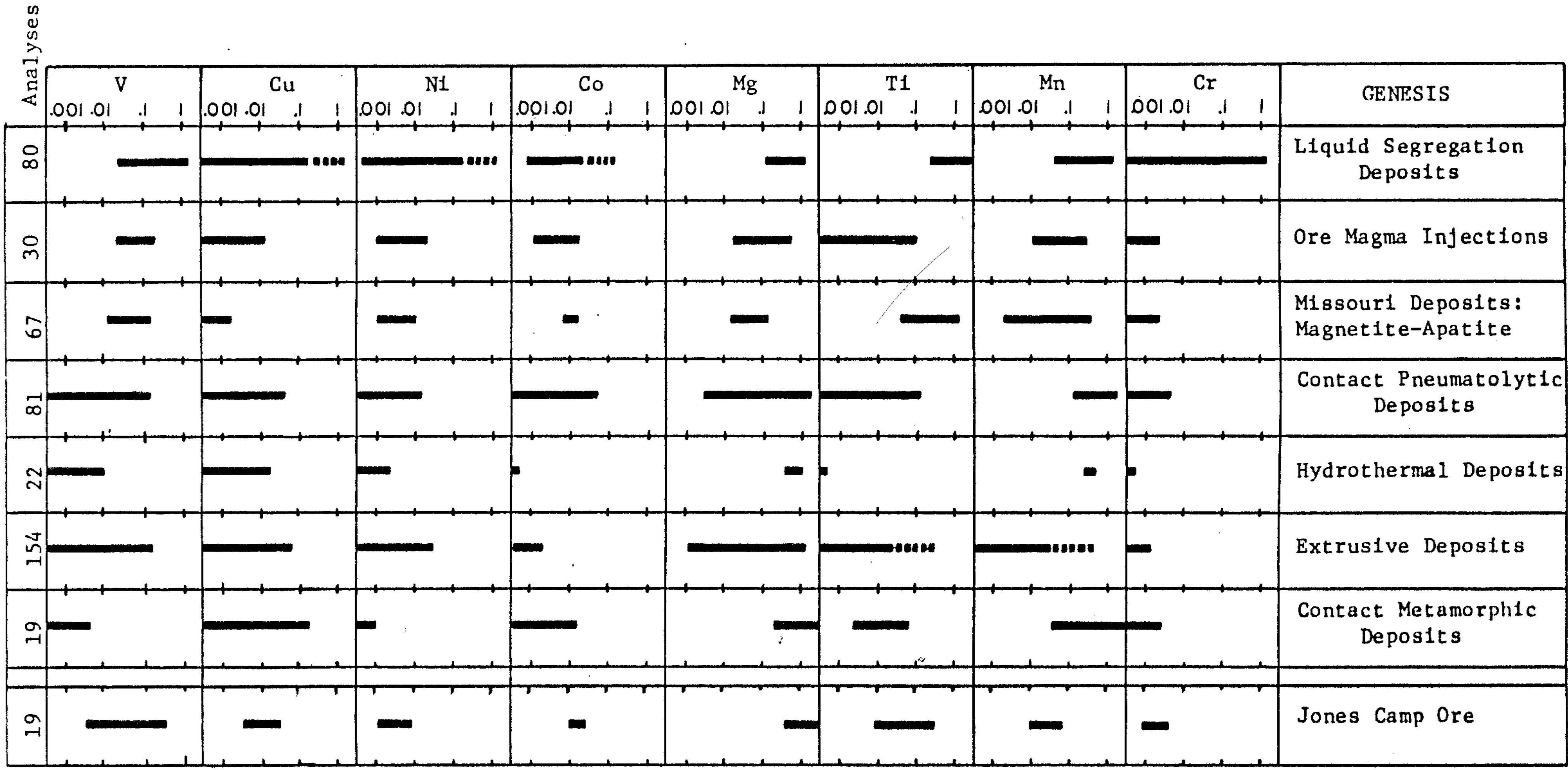


Figure 11. The range of trace element content in magnetites from numerous types of magnetite deposits worldwide as compared to the Jones Camp ores. Data reproduced from Kisvarsanyi and Proctor(1967).

were carried out by emission spectrography. This method, under ideal working conditions, is accurate to +/- 100 percent. The present author found the reliability of this approach to be very poor, having very limited application in quantitative analysis.

3. A single deposit may exhibit several types of ore so that the range of values shown may represent more than one ore type. There are several instances in the literature where more than one model was proposed for a single deposit (Frietsch, 1970; Kisvarsanyi and Proctor, 1967; Park, 1972).

Comparison of Jones Camp Ore With Three Types of Magnetite Ore

Kiruna-type magmatic injection, contact metasomatic, and hydrothermal models of magnetite genesis show distinct to somewhat vague geochemical signatures which are useful guides in classifying a deposit of uncertain origin.

Kiruna-Type Apatitic Ore and Associated Ores of Magmatic Origin

The Swedish apatite-iron deposits from which the

Kiruna-type was named have long been thought to be of magmatic origin (Geijer, 1967; Frietsch, 1978). Geijer and Odman (1967) described in detail these and other deposits throughout the world which they classified as Kiruna-type; the Pilot Knob, Iron Mountain and the Pea Ridge deposits of Missouri, the Cerro Mercado deposit of Mexico, numerous deposits in Chili, Peru (including the El Laco magnetite flows) and others of the Pacific Basin, deposits in Norway and Finland, some deposits of the northern Adirondacks (Mineville), the Iron Springs deposit of Utah and several others have been described in the literature as having features in common with the Kiruna deposits.

The Kiruna ores consist of three types; the apatite iron ores, the Hauki-type ores and the skarn ores, however only the apatite ores are considered to be magmatic injection deposits and will be referred to as Kiruna-type. The other types will be discussed with the hydrothermally related ores.

The Kiruna-type ores have several features in common:

1. They are all quite rich in phosphorus (usually one to two percent but range from .01 to five percent).

2. They all occur in volcanic sequences or within igneous host rocks (except for the limestone association with the Iron Springs ores).

3. The titanium content is quite low, usually less than 0.1 percent.

4. The ore forms long, tabular bodies or braided networks of veins in the wall rock which have been termed "ore breccia".

Table 5 gives the range and mean trace element values for several Kiruna-type deposits or groups of deposits along with the range and mean values for the Jones Camp magnetite ore. Also included are values for the accessory magnetite in the dike.

While the Kiruna-type ores seem to form a geochemically coherent group, one type of magnetite deposit of magmatic association is very distinct. These are the titaniferous magnetites, common to the northern Adirondack region. Although little trace element data is available for these deposits, what is available has led several authors to suggest that these deposits are of an early magmatic origin (Buddington, 1955; Lister, 1966). The Kiruna ores have generally been associated with late magmatic processes.

Early Magmatic Ores

According to Lister (1966), the concentration of certain trace elements in magnetite ore is a function of the temperature of formation and the process of ore

DEPOSITS	Cr	Mg	Ti	Co	Cu	Zn	V	Mn	Ni	Ca(%)	P(%)
Missouri											
Pea Ridge	1	436	1050	20	2	100	625	732	55	-	-
Iron Mtn.	4	1295	6340	45	8	130	1195	3743	37	-	-
Bourbon	1	1060	3300	58	1	127	1385	634	57	-	-
Range	0-20	-	500-10000	<125	0-20	-	500-2000	<200-5000	15-125	-	-
N. Sweden	10	1900	1500	120	40	100	1300	700	220	0.5	1-2
Range	< 20	180-12000	<600-6000	<20-260	<10-180	<50-350	350-2500	<200-2400	60-800	.1-4.0	.01-5.0
Misi, Finland	< 20	5000	700	110	30	50	1000	600	280	-	-
Range	< 20	3000-12000	<600-1200	40-150	<10-70	-	600-1500	<200-800	80-500	-	-
Jones Camp Ore	15	19000	800	123	189	106	950	350	28	1.2	.11
Range	8-38	3800-33500	<300-3125	93-180	53-383	19-838	<125-5250	150-613	13-81	.3-3.5	0-.17
Jones Camp Dike (acces. mag.)	32	2750	25000	109	61	66	3165	1260	50	1.0	-

Table 5. Trace element concentrations (range and mean values) of several Kiruna-type apatite ore deposits compared with trace element data from the Jones Camp area. Data reproduced from Frietsch(1970). All values in ppm, except where indicated otherwise.

concentration.

Buddington (1955) first proposed that the titanium content of titaniferous magnetite might be used as a geothermometer. He studied many of the discordant and concordant titaniferous magnetite deposits of the Adirondacks as well as their igneous host rocks and made the following observations (1955):

1. The titanium content of magnetite decreases with a decrease in temperature of ore formation (based on petrographic observations of the host rock).

2. The titanium concentration in accessory magnetite in the igneous ore-host rock is very similar or slightly lower than in the ore magnetite.

Based on these observations Buddington (1955) suggested that the ores are genetically related to their host rocks by some process of early segregation of the magnetite (i.e. filter pressing or immiscible segregation).

Lister (1966) showed that selected trace elements (Ti, V, Cr, Mg and Mn) in magmatically related ores can be useful in distinguishing late magmatic from early magmatic iron ore deposits; studies focused on the titaniferous magnetites of the Adirondack region. Lister (1966) found that early formed magnetite contained greater amounts of Cr and V than late formed magnetite while early formed ilmenite had greater amounts of Mg and lesser amounts of Mn than late forming ilmenite. If the Ti content in magnetite (as exsolved ilmenite) decreases with a decrease in temperature (Buddington, 1955) we should see a general decrease in Cr, V and Mg as well.

Late Magmatic Ores

Late magmatic ore segregation has been proposed by several authors (Frietsch, 1978; Bateman, 1951; Geijer, 1930; and others) as a likely means of oxide ore formation and is suggested as the most likely origin for the Kiruna-type magnetite deposits. While many of the trace element values bear a resemblance to the Jones Camp data, there are some contrasts:

1. the mean Ti values of these Kiruna-type deposits are considerably higher (except for those of Misi, Finland) than in the Jones Camp ores.

2. the mean Ni values are considerably higher (expecially the Swedish and Finnish ores) than the Jones Camp ores.

3. the Cu values are considerably higher in the Jones Camp ores; above the range of most Kiruna-type ores.

Distinction in Processes Between Early and Late Oxide Accumulation

No clear distinction is made in the literature between the processes of ore concentration or segregation of early versus late magmatic magnetite ores. Two common models for the accumulation of iron include gravitational settling of iron (as immiscible oxides or as magnetite crystals) or as a residual liquid followed by filter pressing, a model proposed by Osborne (1928). While Ramberg (1948) considers some of these deposits to have formed by the migration of iron during metamorphism, there are many problems associated with this mechanism. Because Ramberg's (1948) model is not widely accepted in the literature, it will not be considered in this paper.

The problem with a geochemical approach in distinguishing these mechanisms of iron accumulation stems from the lack of theoretical and experimental data. While the concordant magnetites of layered complexes are geochemically consistent with a mechanism of gravitational settling of early formed oxide crystals, this mechanism is not considered applicable to discordant bodies. The problem of mobilizing a pure crystal segregate has been cited in the literature (Lister, 1966).

Philpotts (1978) cites evidence for the formation of immiscible iron oxides in tholeiitic magmas and that such immiscibility occurs early enough in magmatic crystallization to take part in the differentiation processes. While immiscibility is a practical mechanism for iron ore formation, geochemical modelling of this process is at present rarely attempted due to the absence of partitioning data between immiscible liquids. It is unknown whether partitioning of trace elements between oxide and silicate liquids is an important process.

Hydrothermal Ores

Hydrothermal ore deposits are distinguished from "skarn" deposits (also hydrothermally related) by the lack of an adjacent igneous source of the fluids; the iron could be derived from any single or multiple source although it is generally considered to be derived from host rocks (igneous or sedimentary) by scavenging meteoric waters, often driven by a nearby thermal source. Quantitative data on trace element behavior in hydrothermal regimes is not well documented. What little data is available has generally been applied to rare-earth elements; however it is evident that transition element concentrations in hydrothermal systems must be very low due to the lack of hydrothermal ore deposits which contain these elements.

Hegemann and Albrecht (1954) give trace element data from various hydrothermal magnetite deposits throughout the world (Table 6). These values are considerably lower (except for Mn and Cu) than values in the Jones Camp ores.

Skarn Ores

Magnetite skarn deposits have been described by various authors as "contact metasomatic", "contact pneumatolitic", "pyrometasomatic", etc... . Most magnetite deposits that fall into this category have several features in common:

1. an association with an adjacent igneous body from which hydrothermal fluids are believed to have emanated.

2. replacement by magnetite of limestone, dolomite or limey rocks which are in contact with, or very near the intrusive.

3. well developed alteration zoning peripheral to the intrusive body due to the release of large amounts of hydrothermal fluids ("a sweating out") upon contact or during crystallization of the intrusives.

4. evidence for the movement of hydrothermal

	Cr	Mg(%)	Ti	Co	Cu	Zn	V	Mn(%)	Ni	Ca(%)
Hydrothermal Deposits	0-2	.4-1.0	0-2	0-2	0-150	10	0-100	.2-.5	0-20	-
Jones Camp Ore	15	1.9	800	123	189	106	950	.035	28	1.2
Range	8-38	.38-3.35	300-3125	93-180	53-383	19-838	125-5250	.015-.061	13-81	.3-3.5
Jones Camp Dike (acces. mag.)	32	.28	25000	61	66	3165	1260	.005	109	1.0

Table 6. Trace element concentrations (range and/or mean values) of several hydrothermal iron deposits worldwide compared with trace element data from the Jones Camp area. Data reproduced from Frietsch(1970). All values in ppm. except where indicated otherwise.

> fluids outside the early consolidated border in the form of selvages. This would be particularly true of late magmatic fluids.

Table 7 is a compilation of trace element data from various skarn deposits throughout the world (Frietsch, 1970). The wide range of values from various skarn deposits probably reflects the great diversity of physical and chemical conditions during ore formation. Trace element values of the Jones Camp ores fall well within the wide range of values reported for skarn deposits; however many of the values reported for the Kiruna-type magmatic injection deposits fall into this range as well. This wide range of trace element values in skarn deposits may be, in part, due to more than one ore type within a single deposit. While Kiruna ores are predominately magmatic in character, they exhibit many features common to hydrothermal and metasomatic deposits (i.e. replacement textures and extensive hydrothermal alteration). These have been termed Hauki or skarn ores by Frietsch (1970). Deposits which have been represented in the literature as skarn deposits may as well exhibit characteristics typical of magmatic deposits such as the Iron Springs deposits in Utah (Frietsch, 1970). It may be that because many of these ores are often so complex, the geochemical values which represent them may in fact represent a wide range of ore types.

DEPOSITS	Cr	Mg	Ti	Ni	Co	Cu	Zn	V	Mn	Ca
Franklin, NJ			Tr				500		3080	
Mineville, NY		Tr	Tr							Tr
Sjögruvan, Swed.		5400	24						1386	200
Elba, Italy			234-618						462-2618	
Different	0-90	48-42000	0-1020	0-180	0-500	0-150	0-9000	0-1500	1000-2000	
Siberia, USSR		0-55800	0-17400							
W. Siberia, USSR							800-2800			
Bisberg, Swed.	140	1080	300					70	385	70
W. Siberia, USSR		0-10740	0-4560						154-1586	
Mt. Hope, NJ	10-13		3120-3240	40-50	22-30			350-370		
Jones Camp Ore	15	19000	800	28	123	189	106	950	350	12000
Range	8-38	4800-33500	<300-3125	13-81	93-180	53-383	19-838	<125-5250	150-613	3000-35000
Jones Camp Dike (acces. mag.)	32	2750	25000	109	61	66	3165	1260	50	10000

Table 7. Trace element concentrations (range and/or mean values) of several contact-metasomatic iron skarn deposits compared with trace element data from the Jones Camp area. Data reproduced from Frietsch(1970). All values in ppm.

Alteration Related to Mineralization

Many ore deposits can be characterized by the types of alteration they display. A very reactive ore solution is likely to develop much more extensive alteration than a deposit in which solutions played little part in the ore genesis (i.e. ore magma).

Alteration associated with the Jones Camp deposit is best developed within the border facies of the Jones Camp Dike or where mineralization has only partially replaced sedimentary host rock and rarely extends more than a few inches beyond the mineralized contact. Alteration associated with mineralization within sedimentary host rocks is very similar to that found in the border facies of the dike. Tremolite and actinolite are by for the most abundant secondary minerals while sericite, chlorite, epidote and garnet are less commonly observed. Nogueira (1971) identified some garnets as andradite and also noted the development of minor talc, cordierite and acmite in the contact zone.

Tremolite and actinolite are best developed in sandstones. Plate 16 shows a mineralized, brecciated sandstone where the breccia fragments are almost completely altered to tremolite and actinolite. A few quartz and feldspar grains are still preserved.

Limestone contacts are generally knife-edge sharp with little secondary mineral development. Minor thermal metamorphism is indicated by the presence of recrystallized limestone at the contact.

Gypsum which has undergone replacement has generally resulted in a low grade ore. Secondary minerals are not abundant, the gangue consisting principally of unreplaced gypsum with minor tremolite.

Non-mineralized dike contacts are similarly quite fresh, showing little evidence that extensive high temperature hydrothermal activity was present outside mineralized zones.

Many Kiruna-type ore deposits including several from the southeastern Pacific Basin show little or no skarn development. Contacts have been described as "knife-edge" between ore and unaltered host rock suggesting that replacement was not an important mechanism of ore emplacement and that a lack of ore fluid is apparent (Park, 1972).

Barnes (1979) outlines a sequence of events which typify skarn development:

1. shallow intrusion of a magma into carbonate sediments (at 700 degrees C to 900 degrees C or higher depending on composition).

2. contact metamorphisim at 700 degrees C to 500 degrees C during crystallization of the magma. At this stage, little skarn alteration will

occur aside from the minor development of light colored calc-silicates in impure limestones and dolomites. Release of CO_2 and H_2O during this stage results in an increase in the porosity of carbonates so that skarn and ore development may occur.

3. at 600 degrees C, skarn development takes place. Hydrothermal solutions are mobilized from the crystallizing magma along with nearby meteoric waters. Skarn develops wherever permeable zones, adjacent to the igneous contact, exist. The skarn minerals which develop are principally a function of temperature and fluid and host rock chemistry. As crystallization of the magma proceeds and the temperature drops, inner peripheral alteration zones are continually being replaced by later stage alteration.

4. at 500 degrees C to 300 degrees C, oxide development occurs. Burt (1974) describes the typical zoning sequence which develops in Ca-Fe-Si skarns where mineralization and skarn development are simultaneous:

intrusive/ magnetite/ andradite/ hedenbergite/
wollastonite/ limestone

Where Mg is present, hedenbergite is often replaced by epidote and olivine (forsterite) is typically present.

When mineralization post-dates skarnification or where there has been extensive late hydrothermal activity, early skarn development is often erased. Garnet alters to calcite, quartz, epidote, chlorite, and oxides; clinopyroxene is usually replaced by calcite, quartz, tremolite, actinolite, chlorite and oxides and wollastonite alters to quartz and calcite (Barnes, 1979).

CONCLUSIONS

The Jones Camp magnetite deposit does not fall into any simple classification of magnetite deposits. In this respect it is typical since many magnetite deposits exhibit features which are best understood when invoking models which take into consideration more than one distinct process. The Kiruna ores are a good example of this. Early investigators established these deposits to be, beyond a doubt, magmatic in nature (Geijer, 1910, 1919). More recent studies regard the Kiruna deposits as being either volcano-sedimentary (Parak, 1975) or of a more complex nature which encompasses intrusive magmatic, hydrothermal and volcano-sedimentary processes (Frietsch, 1970). Multiple processes often best explain the numerous features of these deposits where a single process fails.

Evaluation of Unfavorable Models

Field relationships as well as petrographic and geochemical evidence necessitate ruling out contact metasomatic and magmatic models for the origin of the Jones Camp ore.

Early Magmatic Model

An early magmatic injection model is ruled out for the following reasons:

1. Trace element data from the Jones Camp ore and accessory dike magnetite does not correlate at all with deposits generally referred to as early magmatic. Trace elements, particulary transition elements, should be preferentially incorporated into early formed magnetites, resulting in high trace element concentrations in the ores. Values at Jones Camp are too low. Cu and Zn follow the reverse trend, having a preference for late forming magnetite. Magnetite at Jones Camp is relativily enriched in these elements.

2. According to Buddington (1955) as well as partitioning data, the high concentration of transition elements in these magnetites should be similar to accessory magnetite in their source rock. Buddington has shown these values to be in agreement. No such correlation is found at Jones Camp. Butler´s (1963) Ti values for accessory magnetites in several intrusives of Lincoln County, New

Mexico as compared to associated ore bodies show the same relationship. While all magnetite deposits in the area are intimatly associated with an intrusive, they cannot be genetically related in terms of an early magmatic model.

3. Neybergh (1980) suggests that there is a negative correlation between Ti and V in both early and late formed magnetites. The data is not consistent with an early formed origin if we assume that the Jones Camp Dike and ore are related to the same source. The high Ti content and low V content of the dike-magnetite shows a reverse trend as compared to the Jones Camp ore.

4. Early magmatic deposits are generally associated with very old layered ultramafic complexes or anorthositic bodies.

Late Magmatic Model

A late magmatic origin seems unlikely in view of the following observations:

1. Kiruna-type deposits often exhibit cross-

cutting relationships with their host rocks which would suggest forceful injection. There is little evidence for this at Jones Camp.

2. Late magmatic deposits often contain abundant evidence of mobilizers, in particular phosphorus, of which there is little at Jones Camp.

3. Kiruna-type deposits are generally associated with non-reactive rhyolitic or alkaline-rich volcanic rocks. No such association is found at Jones Camp.

Skarn Model

A contact metasomatic origin is ruled out based on the following observations:

1. Had the Jones Camp deposit formed as a result of skarn development, late stages of crystallization of the Jones Camp Dike should have left evidence for extensive "sweating out" of the dike . There is little evidence of this happening. Mackin (1967) studied the Iron Springs magnetite deposit of southwestern Utah. Deuteric decay of mafic phenocrysts in the

core of a crystallizing magma released iron along tension joints to the exterior of the intrusive. While the development of joints during cooling is a conspicuous feature at Jones Camp, there is no evidence that extensive iron rich solutions moved along these joints or any independent vein system during late stage crystallization.

2. Veinlets of magnetite/hematite can be seen penetrating into both diabase and monzonite dikes where they come into contact with massive ore.

3. There is an almost total lack of skarn development in sedimentary rocks bordering the dike or bordering the pods of magnetite. With the presence of large amounts of dolomite and limestone, we would expect to see large amounts of garnet had large quantities of high temperature Fe-bearing solutions been released from the dike. Only very minor amounts have been observed.

4. Kisvarsanyi and Proctor (1967) show that in contact metasomatic deposits, trace element concentrations in magnetite decrease away from

the igneous source, suggesting a temperature control for ore formation. No such trend in the Jones Camp ores is apparent.

A Model for the Origin of the Jones Camp Deposit

The Jones Camp Deposit appears likely to be related to hydrothermal activity which followed the emplacement of the Jones Camp Dike. These iron-scavenging solutions were not likely a product of the Jones Camp Dike (as would be typical of a contact metosomatic iron deposit) but probably of a meteoric nature.

The dike-sedimentary rock interface most likely provided a channelway for solutions to move up, scavenging iron from the border facies of the Jones Camp Dike. Upon contact of these low temperature iron bearing solutions with lime bearing rocks of the Yeso Formation, release of CO_2 and simultaneous deposition of iron took place. Evidence for a hydrothermal origin is as follows:

1. There is extensive low temperature hydrothermal alteration within the border facies of the Jones Camp Dike while the dike's interior is relatively free from non-deuteric alteration. This suggests that an outside source of hydrothermal fluids was likely.

2. The extensive border-restricted alteration is accompanied by a depletion in iron of up to 4 to 5 percent in the section 18 study area and minor depletion in the section 24 study area. A very conservative estimate shows that only .5 percent depletion of iron from the highly altered border zone would provide enough iron to account for all the ore present at Jones Camp.

3. Ore textures strongly suggest that solutions were responsible for transporting the ore. Coarsely mineralized vugs and disseminated ore accompanied by extensive replacement of early-formed silicate and sulfide minerals is typical of the Jones Camp ore.

Trace element values of the Jones Camp ores are markedly higher than what is thought to be typical of hydrothermal iron ores. This may be largely a reflection of source rock since trace element values in the Jones Camp ore more closely reflect (with the exception of Ti) trace element values of accessory magnetite within the Jones Camp Dike than they do trace element values which are suppose to typify hydrothermal magnetite deposits. Other iron-bearing rocks (the underlying Abo Formation for example) may have contributed to the iron mineralization at Jones Camp which would be reflected in the trace element makeup of these ores.

SUMMARY

The Jones Camp magnetite deposit poses an interesting problem in terms of interpreting the processes of ore formation. Upon casual inspection, one would likely suggest that contact metasomatic processes were responsible for ore formation. Permian sedimentary rocks (particularly limestone and limey sediments) host magnetite-hematite mineralization along their contact with the Jones Camp Dike.

This paper has three major objectives:

1. to interpret the origin of the Jones Camp Dike and how it may be related to the processes of ore formation.
2. to interpret the origin of the mineralizaton at Jones Camp.
3. to determine whether the iron ore holds any economic potential for precious metals.

Modal and major element analyses of the Jones Camp Dike show that the dike is not uniform in its mineralogy, displaying numerous fluctuations in the mineral and oxide content across the dike accompanied by a much broader trend from a monzodioritic core to a dioritic margin. Of the three models considered to explain this trend (secondary

alteration, multiple intrusion and differentiation in situ), only the multiple intrusion model is supported by field, petrographic and geochemical observations. Geochemical studies, in particular, rule out a differentiation in situ model. While secondary alteration may explain some of the trends observed in the highly altered marginal zones of the Jones Camp Dike, this model cannot adequately account for the dike′s overall geochemical development.

Evidence suggests that the Jones Camp Dike is a composite intrusive, formed by multiple episodes of intrusion. The range of mineralogic and compositional types within the Jones Camp Dike can best be related to a fractionating magmatic source.

The mineralization at Jones Camp occurs as lenticular-shaped discontinuous pods which are found adjacent to the Jones Camp Dike as well as associated with the numerous diabase dikes and sills that occur marginal to the central dike. Both diabase and ore postdate the Jones Camp Dike; the ore is the youngest.

Field relationships, textures of the ore and host rocks, mineralogy and trace element concentration in the ore (including Co, Mn, Zn, Cr, Ni, Cu, Ti, V, Mg, Ca, Pt, Au, Ag, and P), were studied in detail and compared with magnetite deposits of various origins worldwide.

Three models were considered for the origin of the mineralzation at Jones Camp:

1. magmatic injection. This includes both the "late" magmatic ores of the Kiruna-type and the "early" magmatic ores or titaniferous magnetites common to the Adirondacks.

2. contact metasomatic. This includes ores in which the source of the iron can be related to a nearby intrusive as the Iron Springs deposits of Utah.

3. hydrothermal. The source of the iron and the solutions carrying the iron is often quite speculative.

Deposits of "early" magmatic origin are characteristically very high in trace element content and often show cross cutting relationships with respect to their igneous host. Late magmatic iron ore deposits, while exhibiting trace element values similar to Jones Camp ore, also show dike-like features within their alkaline-rich volcanic host rocks which suggests forceful emplacement of a magnetite magma. Contact metasomatic deposits show well developed alteration zoning, evidence for the movement of iron out of a nearby intrusive and show an increase in trace element content in ore closest to its thermal source. The present investigation rules out these three models as likely processes of ore formation.

Evidence suggests that disseminated magnetite within the marginal zones of the Jones Camp Dike provided a source for the iron mineralization at Jones Camp. It is postulated that, following emplacement of the Jones Camp Dike and accompanying sills and dikes, hydrothermal solutions rose up along a channelway at the dike-sedimentary rock interface, scavenging iron from the border of the Jones Camp Dike. The low temperature iron-bearing solutions travelled upward until a favorable host rock was encountered; lime-bearing sediments of the Yeso Formation.

It can be shown that only a very small depletion of iron (.5%) from the border facies of the Jones Camp Dike can easily account for all of the iron mineralization present at Jones Camp.

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APPENDIX

A. Precious Metals

B. Petrographic Descriptions of the Jones Camp Ore

C. Petrographic Descriptions of the Jones Camp Dike

Precious Metals

Interest in the Jones property as a possible source of precious metals arose when it was realized that the Jones Camp Deposit bears a resemblance to the White Oaks iron deposits of western Lincoln County, New Mexico in which there is an unclear association of gold and minor silver and platinum group elements. The presence of gold at Lone Mountain has long been known, bearing the marks of numerous small lode and placer workings which still hold interest today.

Ag, Au, and Pt were analyzed by neutron activation analysis.

Gold is the most sensitive peak. Values in the ore are extremely low with only the background levels recorded as the upper limit of concentration. No sample contained greater than 23 ppb (6.7 x 10 -4 oz/ton).

Silver has a very high detectability limit by neutron activation analysis as observed by the high background levels. No sample contained greater than 7.5 ppm (.22 oz/ton).

Platinum was not detectable by neutron activation due to the instruments low sensitivity to this element. Other platinum group elements for which standards were not prepared but are normally associated with platinum and considerably more sensitive (RE-186, OS-191 and IR-192) were not present in concentrations above their detectability limit (less then 100 ppb).

Emission spectrography confirmed the low concentrations of silver. With a detectability limit of 1 ppm, no sample had greater than 3-4 ppm or about .1 oz/ton.

With a detectability of about 5 ppm for gold, no spectral line was observed. Platinum is sensitive down to about 5 ppm while other platinum group elements are sensitive down to 10-50 ppm. No platinum group spectral lines were observed.

Based on these results, it is clear that the Jones Camp magnetite ore holds no economic concentrations of these metals.

Precious Metal Content in the Jones Camp Magnetite Ore

	Au (ppb)	Ag (ppm)
EB 3-1	19	6.8
EB 3-2	20	7.1
EB 3-3	18	5.8
EB 66N	6	7.5
EB 66C	5	7.1
EB 66S	5	7.1
JCS 1	3	3.4
JCS 2	20	6.5
JCS 3	23	7.5
JCS 4	19	6.1
JCS 5	5	6.8
JCS 6	5	6.5
JCS PY	5	7.1
WPS 1	7	6.8
WPS 2	7	5.8
WPN	7	7.5
EB 29	6	6.8
EB 30	6	7.1
EB 47	6	7.1
EB 69	6	6.5

Table A. Background levels for silver and gold in the Jones Camp ore as determined by neutron activation analysis. No samples measured higher than background.

ORE PETROGRAPHY

	% Mag	% Hem	% Maghem	% Py	% Ilm	% Gangue
EB 3-1	50	50				50
EB 3-2	85	13			2	10
EB 3-3	98	Tr		2		50
EB 66N	90	5	5		Tr	30
EB 66C	40	5	55		Tr	10
EB 66S	80	20				60
JCS 2	96	4				40
JCS 3	90	7	3	Tr		25
JCS 5	85	10		5	Tr	50
JCS 6	90	10		Tr		60
JCS PY	Tr	82	3	15		3
WPS 1	10	90			Tr	30
WPS 2	50	50			Tr	20
WPN	70	30				15
EB 47	85	10	5			35
EB 69	20	70	10		Tr	35

Table B. Percentage of major minerals in the Jones Camp ore. Ore percentages reflect percent of total ore minerals.

Ore Textures

EB 3-1	At high power, magnetite can be seen altering to hematite as much of the sample is anisotropic. Abundant euhedral (hexagonal, some cubic) crystals which are replacements of quartz grains and probably pyrite. Ore host rock is sandstone.
EB 3-2	Large euhedral (cubic) grains of hematite dispersed among smaller grains of magnetite. Magnetite grains often have exsolved ilmenite needles and are generally rimmed by magnetite. Hematite has replaced pyrite. Ore host rock is gypsum.
EB 3-3	Replaced host rock appears to have been gypsum. Pyrite occurs as a few 1 mm. veinlets. Minor hematite is secondary.
EB 66N	Magnetite shows minor martitization. Minor maghemite occurs interstitially among magnetite crystals. Trace amounts of exsolved ilmenite within magnetite. Sandstone is host rock.
EB 66C	Maghemite occurs interstitially among magnetite crystals while magnetite is often rimmed by hematite (martite) and contains martite and ilmenite along its crystallographic planes. Limestone is the probable host.
EB 66S	Martite is developed where magnetite comes into contact with gangue minerals. Limestone is the host rock.
JCS 2	Gypsum appears to have been the host rock. Minor martitization of magnetite.
JCS 3	Maghemite and hematite often form rims around gangue material where magnetite comes into contact. Development of hematite along crystallographic planes also common. Minor ilmenite within magnetite crystals. Gypsum or limestone host.
JCS 5	Considerable amount of gypsum gangue with ore occurring as thickly disseminated subhedral to anhedral magnetite grains. At high power these grains can be seen altering to martite. Five percent pyrite occurs in a few small veins or as fine disseminations showing minor replacement by magnetite.

JCS 6	Gypsum is the ore-host. Trace pyrite as fine disseminations.
JCS PY	This ore sample contains about fifteen percent pyrite which shows extensive replacement by maghemite and hematite along crystal fractures or as concentric bands around pyrite crystals. Pyrite is interstitial among massive hematite (probably martite). Very minor inclusions of magnetite in hematite. Gypsum is the ore host.
WPS 1	Sample shows ore-diabase contact. Magnetite and hematite are intimately intergrown. Small veinlets of hematite can be seen penetrating diabase. Ore host is limestone or gypsum.
WPS 2	At high power, magnetite can be seen altering to hematite along fractures in grains or along crystallographic planes. Magnetite grains grade from anhedral to well developed six sided polygons. Minor exsolved ilmenite in magnetite crystals. Sandstone has been the replaced rock.
WPN	Very fine grained sample where magnetite has replaced limestone. Martite has developed along crystal borders and along crystallographic planes.
EB 47	Anhedral to subhedral magnetite crystals with scattered grains of hematite which are rimmed by maghemite which in turn is rimmed by gangue material. Hematite is replacing pyrite as it often occurs as cubes. Gypsum is the probable host.
EB 69	Ore minerals have replaced sandstone which occurs as a pendant within the dike. Magnetite can be seen altering to hematite along crystallographic planes. Minor exsolved ilmenite. Magnetite often occurs as euhedral crystals (hexagonal) where quartz crystals have been replaced.

Petrographic Description

Sample # : 4-17-1a

Essential Minerals	%
Plagioclase	81
Clinopyroxene	11.5
Hornblende	5

Varietal Minerals	%
Biotite	1

Accessory Minerals	%
Magnetite	1.5

Secondary Minerals	%
Tremolite	15
Actinolite	5
Calcite	4
Sphene	1
Hematite	3
Finely Divided	30

Plagioclase Composition

Not determined

Textures

Pyroxene and magnetite occur interstitially among plagioclase laths. This slide represents the border facies in which a well developed mottled texture appears in both thin section and hand specimen. This is a secondary feature as described below. Alteration has obscured much of the original texture.

Alteration

Slide is extremely altered,composed of approximately 60% secondary minerals. Tremolite often replaces greater than 90 % of zoned plagioclase and occurs as large masses giving rise to the well developed mottled texture. Large masses of predominantly calcite with actinolite and sphene also contribute to this mottled texture. Plagioclase also shows some replacement by pyroxene. Clouds of seconday hematite form from the breakdown of ferromagnesian minerals.

Rock Classification Fine-grained diorite

Discussion

Petrographic Description

Sample # : 4-17-1b

Essential Minerals	%
Plagioclase	85
Orthopyroxene	8
Clinopyroxene	2

Varietal Minerals	%
Biotite	3
Magnetite	2

Accessory Minerals	%

Secondary Minerals	%
Tremolite	20
Actinolite	3
Calcite	2
Sphene	.5
Hematite	2
Finely Divided	25

Plagioclase Composition

Not determined

Textures

This slide represents the fine-grained to aphanitic mottled border facies. Textures similar to 4-17-1a.

Alteration

Spherical masses which develop the mottled texture are composed principally of tremolite and are depleted in oxides. Large blobs of magnetite often occur in the center of these oxide-depleted zones. Scattered microfractures in the rock contain secondary magnetite. Bulk of slide composed of tremolite and actinolite with minor hematite, chlorite, sericite, magnetite and epidote.

Rock Classification Fine-grained diorite

Discussion

Petrographic Description

Sample # : 4-17-2

Essential Minerals	%
Plagioclase	84
Clinopyroxene	8
Orthopyroxene	4

Varietal Minerals	%
Magnetite	1
Biotite	1

Accessory Minerals	%
Apatite	Tr

Secondary Minerals	%
Tremolite	27
Actinolite	2
Calcite	6
Albite	2
Sphene	3
Olivine	.5
Epidote	4
Muscovite	1
Hem. + Mag.	3
Finely Divided	10

Plagioclase Composition

Not determined

Textures

Most primary igneous textures obliterated by secondary effects. Some magnetite appears to occur interstitially among extremely altered laths of plagioclase.

Alteration

This slide shows a slightly mottled texture as described in 4-17-1b. Plagioclase crystals show from 50 to 80 % alteration to sausserite. Numerous microveinlets of magnetite and calcite occur throughout slide. Magnetite and hematite occur as fine dusty particles resulting from ferromagnesian alteration. Olivine occurs as very euhedral (paramidal) crystals, a common mineral in contact metasomatic zones where magnetite is associated.

Rock Classification Fine-grained diorite

Discussion

Magnetite occurring with calcite in these microfractures suggests that at least some of the magnetite in the border facies of the dike may have been mobilized into the dike after its consolidation

Petrographic Description

Sample # : 4-17-3

Essential Minerals	%
Plagioclase	63
Clinopyroxene	1.7
Orthopyroxene	.8
Hornblende	15.3
Orthoclase	5.2

Varietal Minerals	%
Magnetite	7.1
Biotite	6.8

Accessory Minerals	%
Apatite	.4

Secondary Minerals	%
Tremolite	3.5
Quartz	<1
Albite	<1
Chlorite	<1
Finely Divided	35

Plagioclase Composition

Not determined

Textures

Very minor anhedral grains of pyroxene occur intersititially among well zoned plagioclase laths giving rise to an intergranular texture. Hornblende occurs as large euhedral (six sided) crystals or needles, the first essential mineral to form in the crystallization sequence. Magnetite and apatite occur as euhedral crystals enclosed in host plagioclase crystals.

Alteration

Large masses of tremolite are nonselective in their replacement of primary minerals. Plagioclase is strongly saussuritized, particularly in the case of zoned crystals where secondary minerals make up 30 to 70 % of the total plagioclase volume. Albitization of plagioclase is common. Minor secondary quartz occurs throughout slide.

Rock Classification Diorite

Discussion

Large masses of tremolite, particularly in border facies of dike, suggest that it was subjected to hydrothermal alteration and may be related to ore formation.

Petrographic Description

Sample # : 4-17-4

Essential Minerals	%
Plagioclase	66.7
Clinopyroxene	1.4
Orthopyroxene	2.8
Hornblende	16.5
Orthoclase	5

Varietal Minerals	%
Magnetite	4.4
Biotite	7.4

Accessory Minerals	%
Apatite	.3

Secondary Minerals	%
Tremolite	6.6
Actinolite	Tr
Calcite	.2
Albite	Tr
Sphene	.6
Chlorite	<1
Finely Divided	20

Plagioclase Composition

Not determined

Textures

Slide shows fairly well developed isogranular to subophitic texture. Zoned plagioclase frequently occurs with core of crystals more anorthitic than the borders. Hornblende occurs as euhedral crystals which formed early in the crystallization sequence. Euhedral magnetite and apatite formed early and are surrounded by a host of plagioclase and pyroxene.

Alteration

Zoned plagioclases are quite altered in their centers and show minor albitization. Biotite shows minor alteration along cleavage traces. Small amounts of magnetite occur as a fine dusting throughout the slide. Some magnetite also occurs as lath shaped crystals, replacing either plagioclase or secondary amphiboles. Magnetite often surrounded by or associated with sphene.

Rock Classification Diorite

Discussion

Petrographic Description

Sample # : 4-17-5

Essential Minerals	%
Plagioclase	78.3
Clinopyroxene	4.8
Orthopyroxene	1.8
Hornblende	3.4
Orthoclase	7.6

Secondary Minerals	%
Tremolite	4.1
Actinolite	<1
Quartz	1
Albite	1
Sphene	1.1
Epidote	.5
Finely Divided	15

Varietal Minerals	
Magnetite	3.8
Biotite	Tr

Plagioclase Compsition

An 43

Accessory Minerals	%
Apatite	Tr

Textures

This slide has an intergranular to subophitic texture. Most magnetite crystallized early, occurring as euhedral crystals within a host of pyroxene or plagioclase.

Alteration

Alteration not as strongly developed in this slide as compared to border facies. Cores of zoned plagioclase are quite altered however the total percent of secondary minerals within plagioclase crystals runs between 10 and 30 %. Magnetite often seen replacing minerals indiscriminately. Alteration of plagioclase is common. Pyroxene shows minor alteration to hornblende, magnetite, actinolite and hematite.

Rock Classification Diorite to monzodiorite

Discussion

Petrographic Description

Sample # : 4-17-6

Essential Minerals	%
Plagioclase	72.7
Clinopyroxene	4.3
Orthopyroxene	1.1
Hornblende	5.7
Orthoclase	5.7

Varietal Minerals	%
Magnetite	2.5
Biotite	2.2

Accessory Minerals	%
Apatite	Tr

Secondary Minerals	%
Tremolite	3.4
Actinolite	4.4
Calcite	Tr
Sphene	1.2
Chlorite	Tr
Hematite	1.2
Finely Divided	10

Plagioclase Composition

An 38

Textures

Similar to 4-17-5. Hornblende generally occurs as large euhedral crystals except where it is found as an alteration product of pyroxene.

Alteration

Saussuritization of plagioclase more evenly distributed throughout weakly zoned crystals, consuming about 20 % of the crystal. Biotite often seen altering to actinolite and hematite. Hornblende shows some alteration to tremolite, actinolite and hematite. Pyroxene commonly alters to hornblende.

Rock Classification Diorite

Discussion

Petrographic Description

Sample # : 4-20-7

Essential Minerals	%
Plagioclase	66.3
Clinopyroxene	6.9
Orthopyroxene	.6
Hornblende	7.8
Orthoclase	10.4

Varietal Minerals	%
Magnetite	5.3
Biotite	2.3

Accessory Minerals	%
Apatite	.3

Secondary Minerals	%
Tremolite	1.0
Actinolite	1.6
Albite	Tr
Sphene	Tr
Olivine	1
Chlorite	.9
Hematite	.4
Finely Divided	30

Plagioclase Composition

An 49

Textures

Clinopyroxene seen crystallizing after plagioclase developing a subophitic texture. Apatite occurs as very euhedral grains enclosed by hornblende. Orthopyroxene crystallizes before the plagioclase. Hornblende generally crystallized before or during plagioclase

Alteration

Zoned plagioclase 10 to 70% altered. Clinopyroxene alters readily to hornblende, actinolite and magnetite.

Rock Classification Monzodiorite

Discussion

Petrographic Description

Sample # : 4-20-8

Essential Minerals	%
Plagioclase	74.8
Clinopyroxene	.7
Orthopyroxene	.6
Hornblende	6.9
Orthoclase	13.4

Varietal Minerals	%
Magnetite	3.2
Biotite	.3

Accessory Minerals	%

Secondary Minerals	%
Tremolite	1.3
Actinolite	.9
Quartz	1.0
Albite	1.0
Sphene	.3
Chlorite	.3
Finely Divided	25

Plagioclase Composition

An 36

Textures

Similar to 4-20-7. Minor euhedral magnetite; most occurring as serrated or broken looking fragments. Large plagioclase crystals surrounded by a finer matrix of late-crystallizing material and alteration products. Hornblende occurs as large, euhedral crystals which crystallized before plagioclase.

Alteration

Hornblende is the least altered of the essential minerals, however it does show some replacement by tremolite. Plagioclase shows as much as 80 % alteration (often to tremolite) and generally weakly zoned. Quartz is a secondary mineral and is usually associated with open spaces in the rock.

Rock Classification Monzodiorite

Discussion

Petrographic Description

Sample # : 4-20-10

Essential Minerals	%
Plagioclase	73
Clinopyroxene	.6
Hornblende	10.9
Orthoclase	10.5

Varietal Minerals	%
Magnetite	3.6
Biotite	1.4

Accessory Minerals	%
Apatite	.1

Secondary Minerals	%
Tremolite	.7
Actinolite	2.6
Quartz	<1
Albite	Tr
Sphene	.7
Olivine	Tr
Chlorite	.4
Hematite	Tr
Finely Divided	30

Plagioclase Composition

An 40

Textures

Inequigranular, intergranular to isogranular texture. Some large, early formed euhedral magnetites show relict ilmenite lamellae now altered to sphene.

Alteration

Well zoned plagioclases show up to 70 % degradation, particularly in cores where much has been replaced by tremolite with some actinolite and albite. Tremolite also occurs as large masses radiating outward where it is often associated with other secondary minerals; particularly sphene and actinolite. Pyroxene seen altering to hornblende which in turn alters slightly to actinolite. Exsolution lamellae in magnetite have been altered to sphene.

Rock Classification Monzodiorite

Discussion

Petrographic Description

Sample # : 4-20-11

Essential Minerals	%
Plagioclase	79
Clinopyroxene	7.3
Orthopyroxene	1.0
Hornblende	.2
Orthoclase	11

Varietal Minerals	%
Magnetite	1.3

Accessory Minerals	%
Apatite	.2

Secondary Minerals	%
Tremolite	11.1
Actinolite	3.6
Calcite	2.0
Albite	<1
Sphene	1.9
Olivine	1.3
Chlorite	.2
Hematite	1.1
Finely Divided	30

Plagioclase Composition

An 38

Textures

Texture similar to 4-20-10

Alteration

Plagioclase shows 40 to 50 % alteration to sericite, tremolite, calcite and actinolite, although it is commonly replaced only by large masses of tremolite. Magnetite is often surrounded by or associated with sphene or calcite in open spaces. Clinopyroxene extensively altered to actinolite, hematite and calcite. Large euhedral olivine crystals associated with vugs which often show iddingsite alteration.

Rock Classification Monzodiorite

Discussion

Petrographic Description

Sample # : 4-20-12

Essential Minerals	%
Plagioclase	77
Clinopyroxene	10.0
Orthopyroxene	7.0
Hornblende	.2
Orthoclase	5

Varietal Minerals	%
Magnetite	.2
Biotite	.5

Accessory Minerals	%
Apatite	Tr

Secondary Minerals	%
Tremolite	5.4
Actinolite	5.9
Calcite	Tr
Sphene	4.5
Garnet	Tr
Hematite	.4
Finely Divided	20

Plagioclase Composition

An 35

Textures

Well developed intergranular texture with inequigranular grain distribution. Magnetite occurs interstitially in finer groundmass suggesting late crystallization.

Alteration

Very large masses of tremolite with minor actinolite give rise to the mottled texture of this rock. Plagioclase does not show the well developed zoning common to the center of the dike so that its alteration is more evenly distributed throughout crystal. Often plagioclase is highly birefringent due to its nearly complete replacement by tremolite. Clinopyroxene has minor alteration to actinolite, hematite and albite. Much of magnetite occurs with calcite in vugs suggesting a secondary nature.

Rock Classification Diorite

Discussion

Grain size is decreasing toward dike border.

Petrographic Description

Sample # : 4-20-13

Essential Minerals	%
Plagioclase	78.4
Clinopyroxene	10.1
Orthopyroxene	6.0

Varietal Minerals	%
Magnetite	5.0
Biotite	.5

Accessory Minerals	%
Apatite	Tr

Secondary Minerals	%
Tremolite	16.8
Actinolite	2.0
Calcite	7.4
Albite	Tr
Sphene	.5
Chlorite	.2
Garnet	Tr
Finely Divided	15

Plagioclase Composition

An 35

Textures

This slide taken from fine-grained border facies of dike showing well developed intergranular texture similiar to 4-20-12. Most of the magnetite has crystallized late, filling the interstices of plagioclase crystals.

Alteration

This rock is extensively altered and difficult to determine the mineralogy. A considerable amount of tremolite is distributed throughout the slide in large masses. Poorly zoned plagioclase shows about 25 to 30 % alteration. Clinopyroxene is often altered to actinolite.

Rock Classification Diorite

Discussion

Petrographic Description

Sample # : 1-13-1

Essential Minerals	%
Plagioclase	76.3
Clinopyroxene	7.6
Orthopyroxene	1.3
Orthoclase	10.6

Varietal Minerals	%
Magnetite	3.8
Biotite	.1

Accessory Minerals	%
Apatite	.3

Secondary Minerals	%
Tremolite	2.2
Actinolite	.9
Calcite	.3
Albite	Tr
Sphene	.6
Olivine	1.6
Garnet	Tr
Finely Divided	15

Plagioclase Composition

An 37

Textures

Fine grained pyroxene occurs interstitially among larger plagioclase laths. Magnetite crystallized late, also occurring as an intergranular mineral.

Alteration

Massive replacement of plagioclase by tremolite occurs occasionally in slide. Zoning of plagioclase not well developed and shows 15 to 20 % degradation to sericite and tremolite. Clinopyroxene extensively altered to actinolite.

Rock Classification Monzodiorite

Discussion

Petrographic Description

Sample # : 1-13-2

Essential Minerals	%
Plagioclase	73.3
Clinopyroxene	6.3
Orthopyroxene	1.1
Hornblende	8.7
Orthoclase	2.2

Varietal Minerals	%
Magnetite	5.4
Biotite	.9

Accessory Minerals	%
Apatite	2.0

Secondary Minerals	%
Tremolite	2.8
Calcite	1.8
Albite	Tr
Sphene	1.5
Olivine	2.5
Chlorite	1.0
Hematite	.2
Finely Divided	20

Plagioclase Composition

Ranges from An 34 to An 58 in core.

Textures

Medium grained with intergranular to subophitic texture. Most magnetite occurs as subhedral grains which crystallized early although some occur as late-forming intergranular material. Euhedral apatite is often contained within plagioclase lathe. Localized zones in slide show a trachytic texture where alignment of plagioclase gives this rock a well developed grain.

Alteration

Some magnetite associated with calcite veins which suggests a secondary origin. Zoned plagioclase have deeply altered cores with secondary minerals making up about 25 % of the total plagioclase content.

Rock Classification Diorite

Discussion

Petrographic Description

Sample # : 1-13-3a

Essential Minerals	%
Plagioclase	84.1
Hornblende	6.3
Orthoclase	7.4

Varietal Minerals	%
Magnetite	2.2

Accessory Minerals	%
Apatite	Tr

Secondary Minerals	%
Calcite	.7
Quartz	1.4
Albite	2.0
Sphene	.5
Chlorite	.5
Finely Divided	20

Plagioclase Composition

An 36

Textures

Quite inequigranular with large, early formed euhedral and needle shaped hornblendes surrounded by smaller plagioclase laths. Magnetite occurs both as early and late formed crystals.

Alteration

Plagioclase shows a 25% alteration to saussurite. This slide quite free from secondary effects compared to border facies rocks.

Rock Classification Diorite

Discussion

Petrographic Description

Sample # : 1-13-3b

Essential Minerals	%
Plagioclase	86.5
Clinopyroxene	2.6
Orthopyroxene	.5
Hornblende	2.1
Orthoclase	5.3

Varietal Minerals	%
Magnetite	2.6

Accessory Minerals	%
Apatite	.2

Secondary Minerals	%
Actinolite	3.3
Albite	Tr
Sphene	1.2
Olivine	.2
Chlorite	.6
Hematite	.6
Finely Divided	25

Plagioclase Composition

An 35

Textures

Similiar to 1-13-3a. Most magnetite crystallized early.

Alteration

Plagioclase frequently alters to saussurite and actinolite. Some plagioclase crystals show a reverse zoning with alteration best developed along the more anorthitic borders.

Rock Classification Diorite

Discussion

Petrographic Description

Sample # : 1-13-3c

Essential Minerals	%
Plagioclase	77.6
Clinopyroxene	6.6
Orthopyroxene	.5
Hornblende	7.5
Orthoclase	3.2

Varietal Minerals	%
Magnetite	4.3
Biotite	.3

Accessory Minerals	%
Apatite	.5

Secondary Minerals	%
Tremolite	1.6
Actinolite	.3
Calcite	2.0
Sphene	.2
Olivine	.8
Chlorite	1.1
Hematite	.3
Finely Divided	25

Plagioclase Composition

An 49

Textures

Isogranular to subophitic texture. Magnetite crystallized both late and early occurring as euhedral crystals within plagioclase and pyroxene crystals and as a fine-grained, interstitial material.

Alteration

Plagioclase strongly saussuritized, particularly in the crystal centers where they are more anorthitic. Much of the hornblende, along with tremolite and actinolite, appears to be a secondary product of pyroxene.

Rock Classification Diorite

Discussion

Petrographic Description

Sample # : 1-13-3e

Essential Minerals	%
Plagioclase	66.7
Clinopyroxene	Tr
Orthopyroxene	Tr
Hornblende	12.5
Orthoclase	15.4

Varietal Minerals	%
Magnetite	5.0
Biotite	.3

Accessory Minerals	%
Apatite	.1

Secondary Minerals	%
Tremolite	<1
Actinolite	3.0
Calcite	Tr
Quartz	.4
Albite	Tr
Sphene	.3
Chlorite	.4
Hematite	.4
Finely Divided	10

Plagioclase Composition

An 37

Textures

Similiar to 1-13-3c. Hornblende occurs as small euhedral grains which are generally enclosed by plagioclase. Slide has an inequigranular, intergranular texture although pyroxene content is very low. Magnetite occurs as early formed, euhedral crystals.

Alteration

Plagioclase replaced by up to 5 % actinolite with minor replacement by tremolite and sphene.

Rock Classification Monzodiorite

Discussion

Petrographic Description

Sample # : 1-13-3f

Essential Minerals	%
Plagioclase	67.2
Hornblende	19.1
Orthoclase	10.6

Varietal Minerals	%
Magnetite	1.6

Accessory Minerals	%
Apatite	1.3

Secondary Minerals	%
Tremolite	3.5
Actinolite	.9
Albite	Tr
Sphene	.7
Olivine	.1
Chlorite	.6
Hematite	1.3
Finely Divided	25

Plagioclase Composition

An 43

Textures

Medium to course grained rock containing numerous large, euhedral magnetite and hornblende crystals. Magnetite has well developed relict ilmenite lamellae which have altered to sphene. Abundant early formed, euhedral apatite.

Alteration

Zoned plagioclase showing approximately 30 % alteration to sericite, tremolite and actinolite. Minor albitization of plagioclase also present. Any pyroxene in rock has altered to hornblende.

Rock Classification Monzodiorite

Discussion

Petrographic Description

Sample # : 1-13-3h

Essential Minerals	%
Plagioclase	86
Clinopyroxene	3.3
Orthopyroxene	.3
Orthoclase	10

Secondary Minerals	%
Tremolite	9.4
Actinolite	4.9
Calcite	1.2
Sphene	<1
Olivine	.4
Hematite	.3
Finely Divided	5

Varietal Minerals	%
Magnetite	

Plagioclase Composition

An 36

Accessory Minerals	%
Apatite	.4

Textures

Fine grained border facies with intergranular texture. Magnetite crystallized late filling intersticies of plagioclase laths. Apatite occurs as small euhedral crystals enclosed within plagioclase grains. Locally, a trachytic texture has developed where plagioclase laths show a preferential orientation. Plagioclase crystals are unzoned, typical of the border facies.

Alteration

Tremolite and actinolite form spherical, optically continuous masses which develop the pseudo-porphyritic texture typical of the border-facies rocks. Microfractures in rock filled with magnetite and calcite would suggest movement of iron into dike. Unzoned plagioclase shows less than 10 % alteration to sericite, tremolite and actinolite.

Rock Classification Monzodiorite

Discussion

The trachytic texture or "flow banding" indicates unidirectional movement of magma during crystallization of dike.

This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Adviser

Kent C. Condie

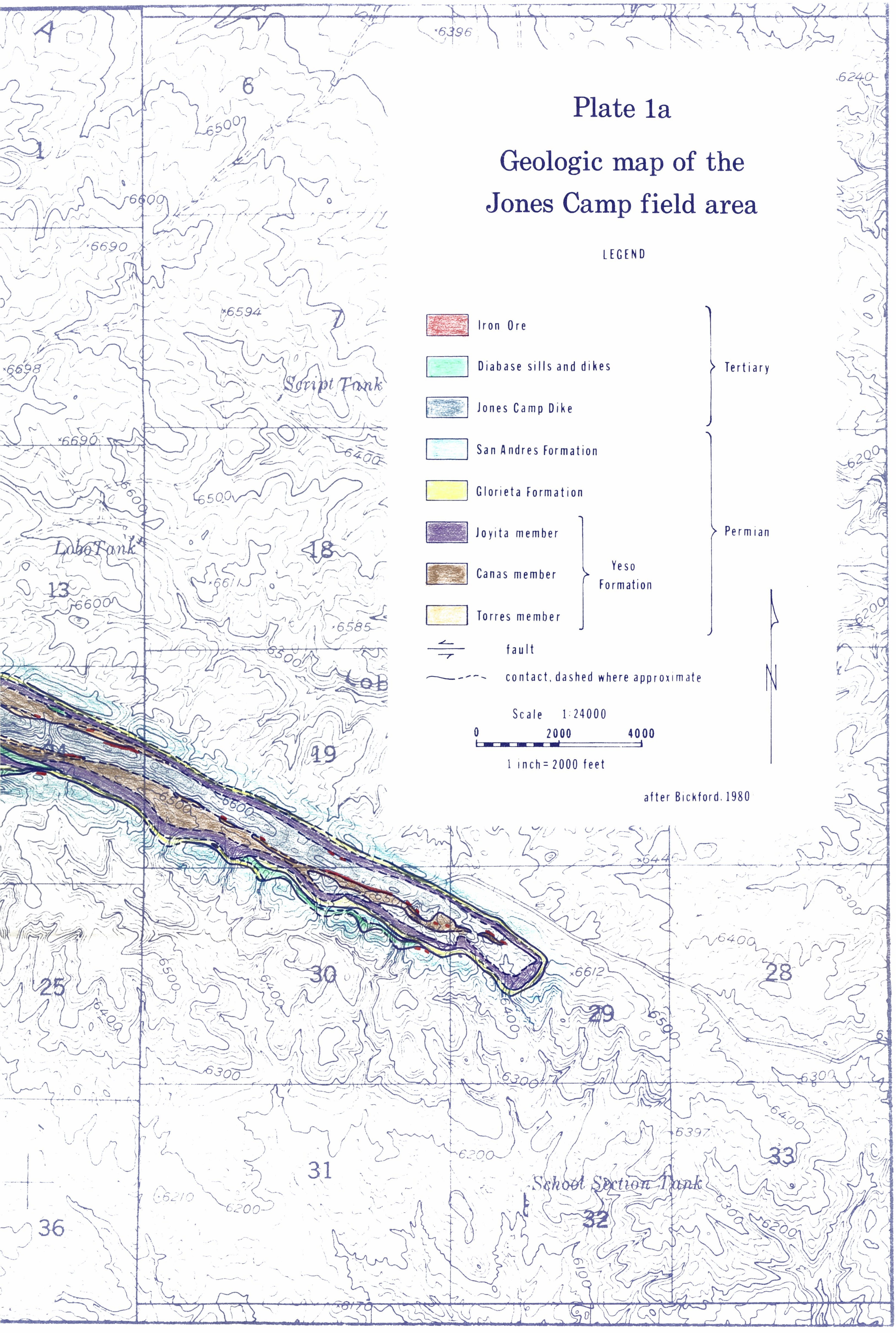
David A. Norman

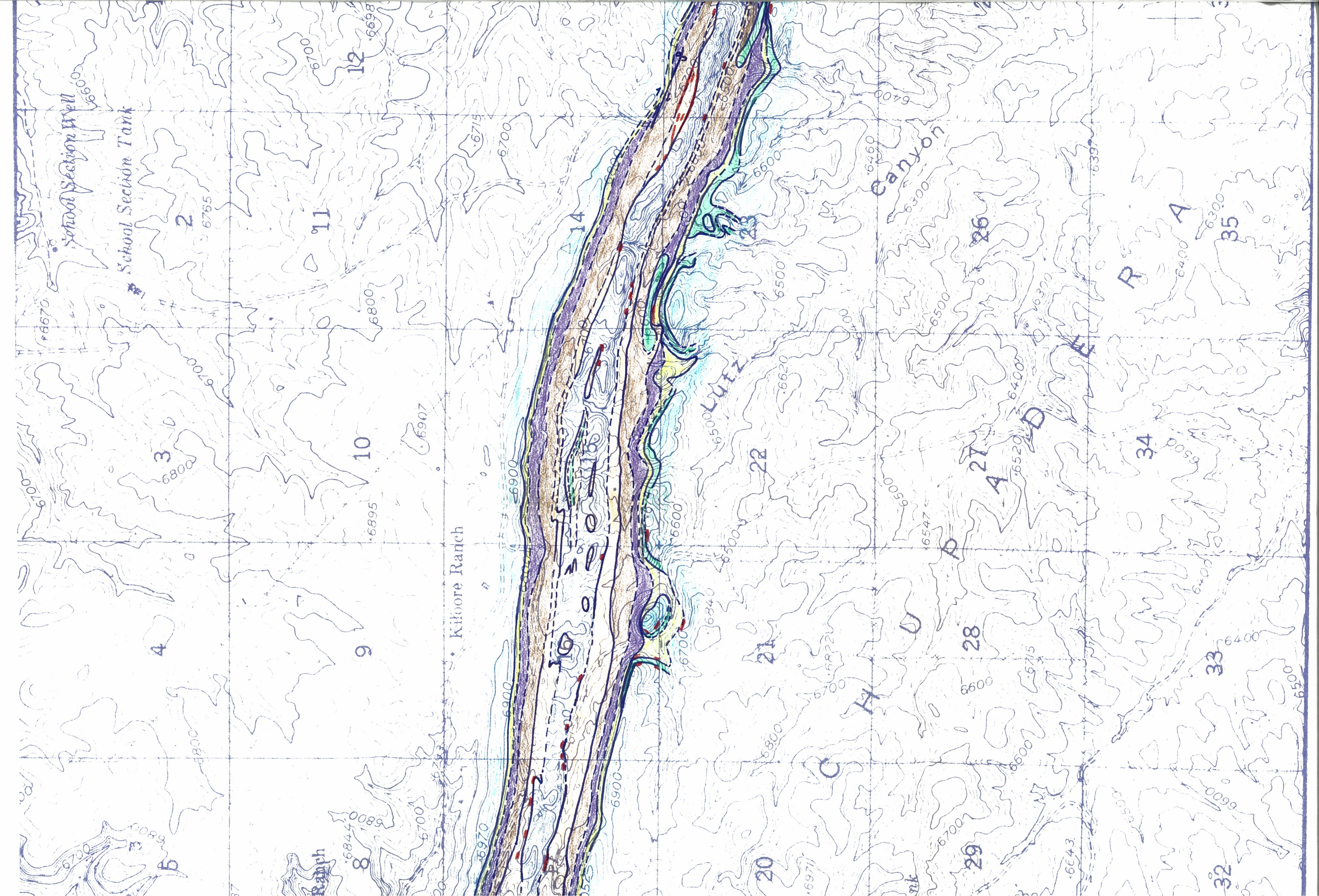
[illegible]

Date

Plate 1a

Geologic map of the Jones Camp field area

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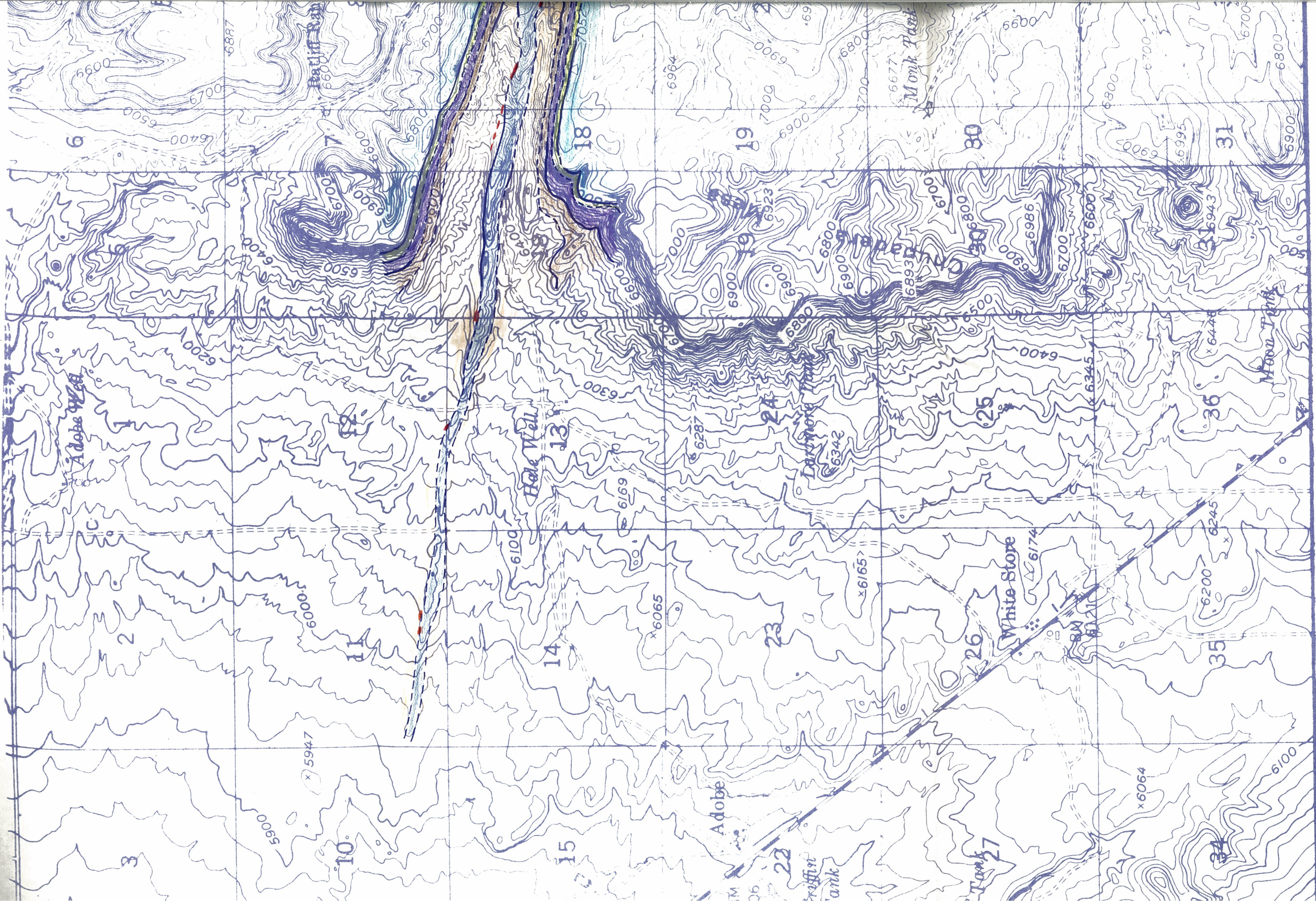
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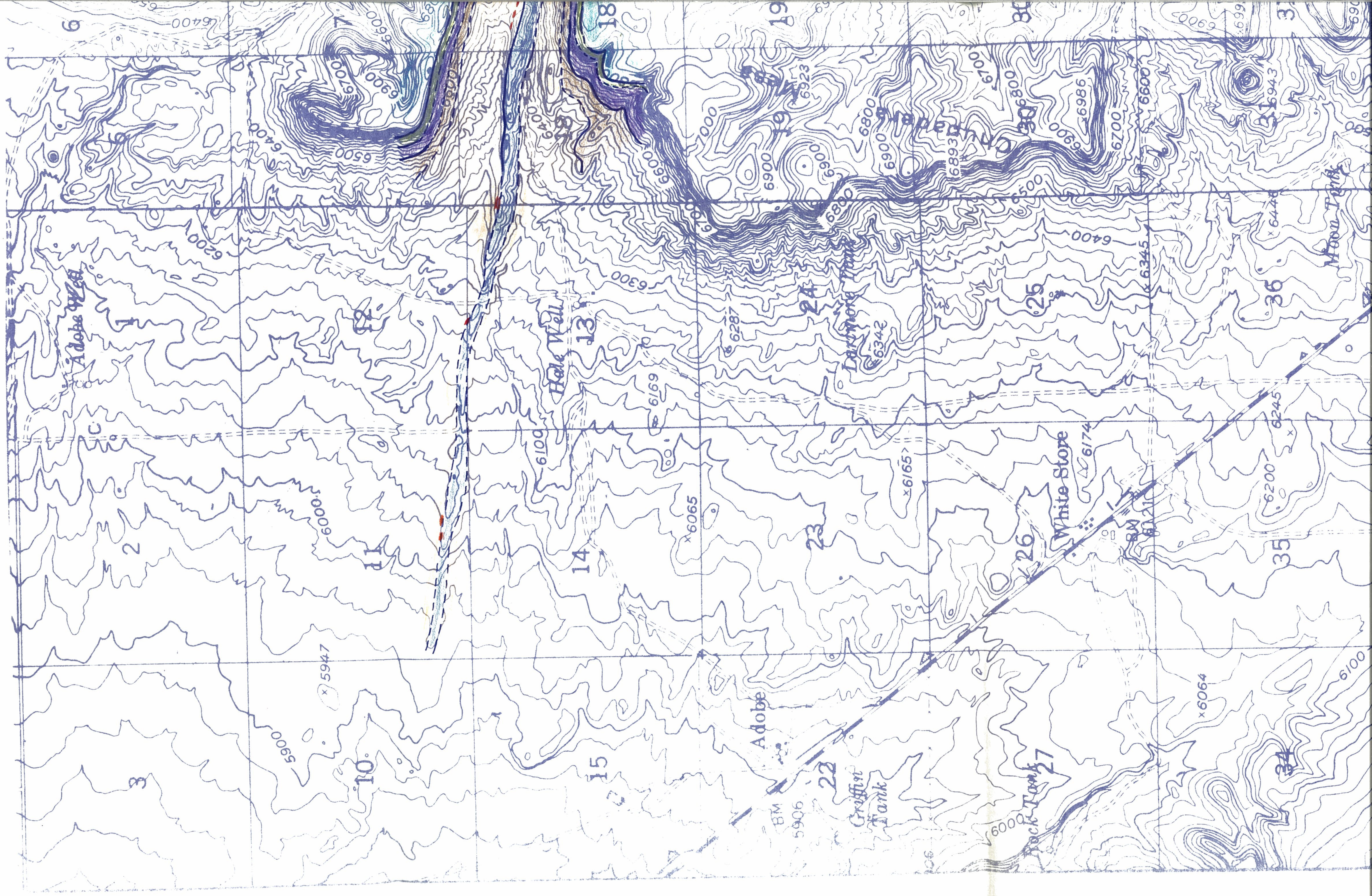Adobe Well
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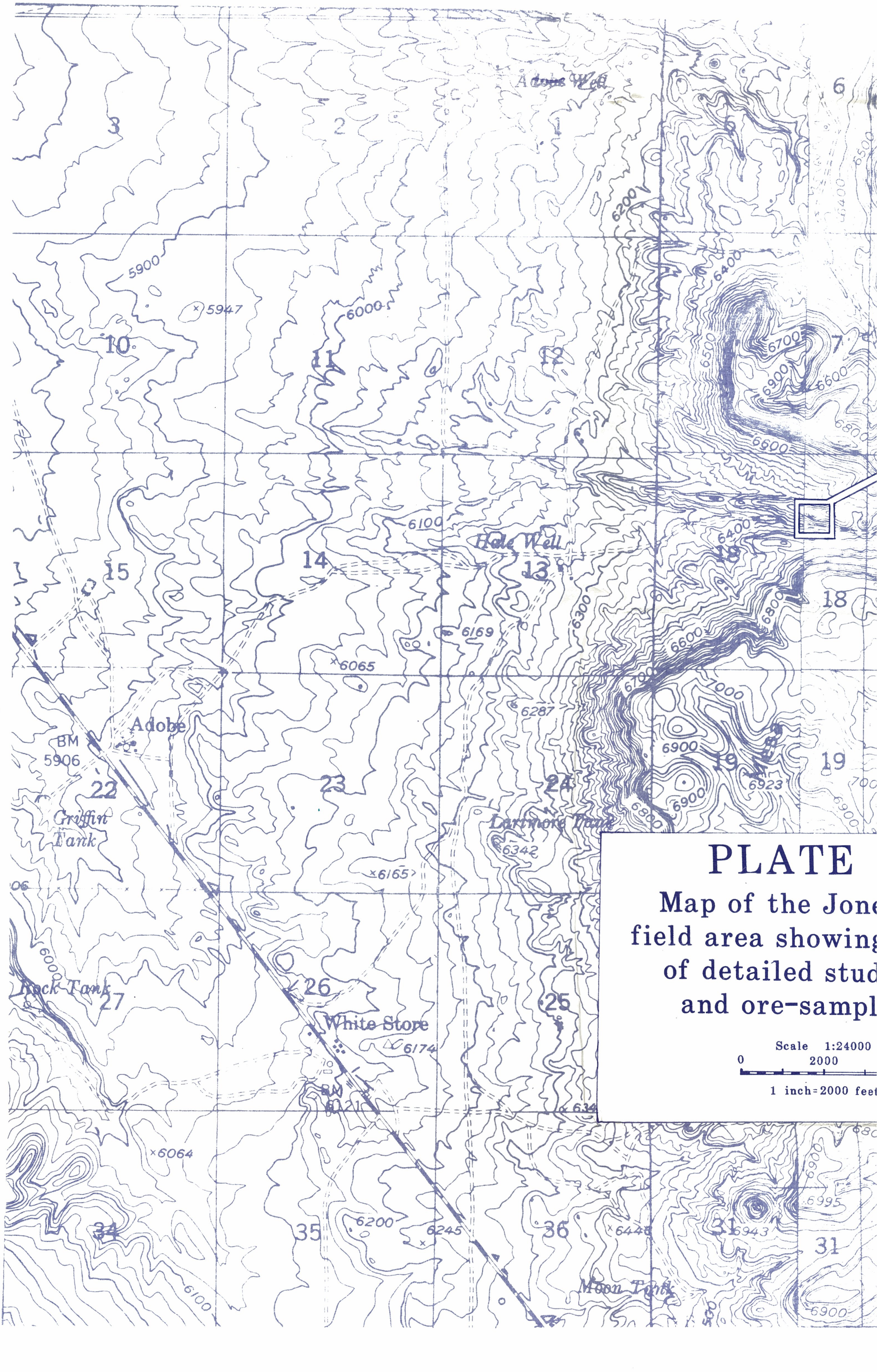

PLATE

Map of the Jone

field area showing

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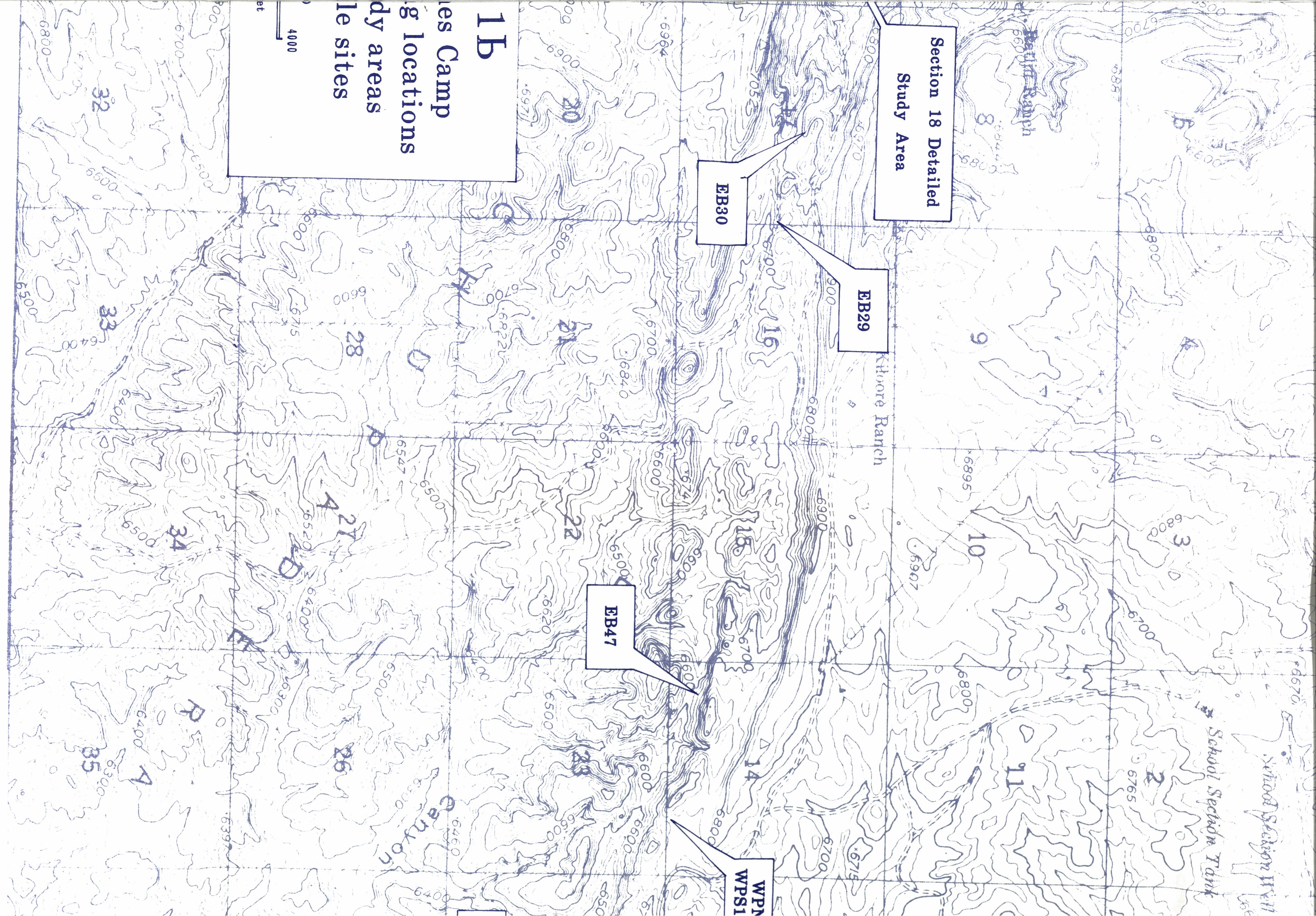
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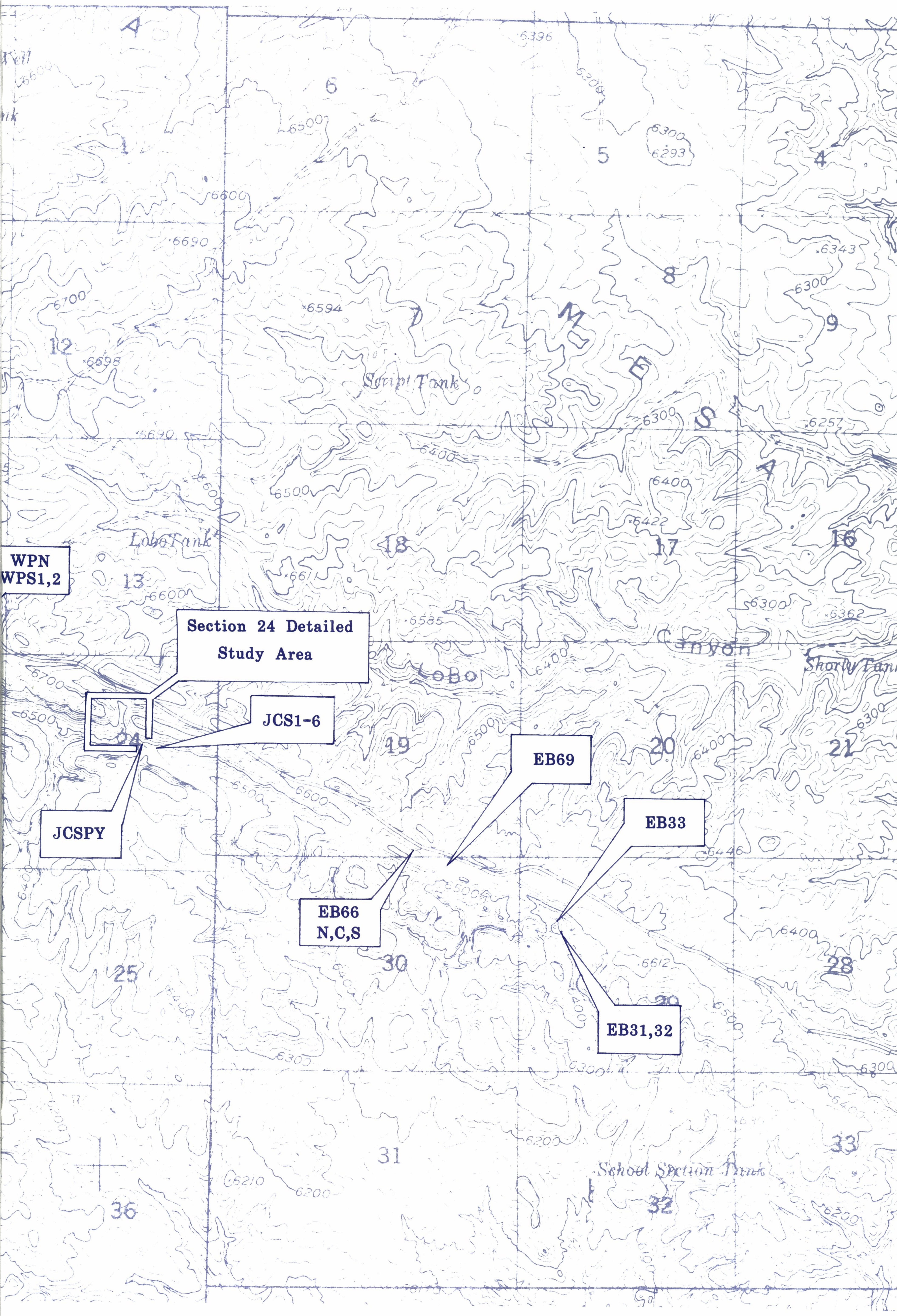
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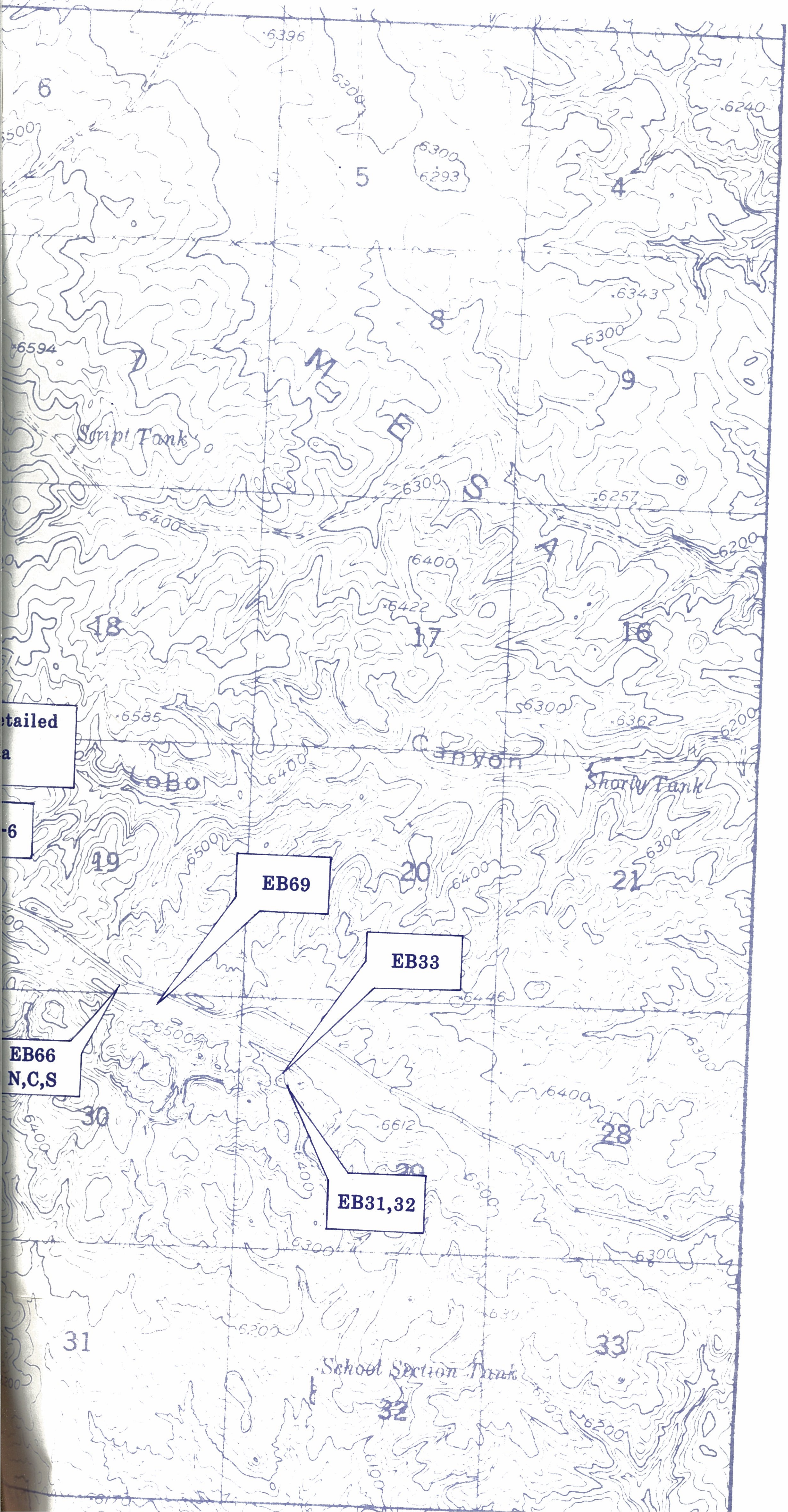

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