STABLE OXYGEN ISOTOPE AND CRYSTALLITE SIZE ANALYSIS

OF ALASKAN CHERTS:

A POSSIBLE EXPLORATION TOOL FOR SUBMARINE

EXHALATIVE DEPOSITS

by

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This work is dedicated

To:

Brownie Harrover
(for her constant encouragement)

To:

Lauri D. Albers
and
Roger M. Ward
(for unselfishly keeping a roof over my head)

To:

Larry Eaton, Tonya English, Tom Gibson
and
all my friends and cohorts at New Mexico Tech
(for their wonderful sense of humor)

Thank you,

Robin D. Harrover

Abstract

Stratiform Pb-Zn mineralization is found within intensely folded and faulted carbonaceous cherts and shales of the De Long Mountains, western Brooks Range, Alaska. The deformation and complex stratigraphy in this area make exploration for deposits difficult. Stable oxygen isotope composition and crystallite size of cherts vary with temperature; therefore, cherts around known submarine deposits (Red Dog and Lik) were analysed to note any changes in $\delta^{18}O$ and crystallite size which would indicate a thermal center.

The difference in $\delta^{18}O$ for fifty cherts ranges from +20.7‰ to +31.8‰. Crystallite size for twenty of the cherts sampled ranges from 522 Å to 3274 Å. Samples having $\delta^{18}O$ less than 24% , and crystallite sizes greater than 1300 Å are within one kilometer of known Pb-Zn mineralization. Not all cherts close to known deposits have low values of $\delta^{18}O$ or large crystallite size; however, our data strongly indicate that cherts anomalously low in $\delta^{18}O$ and/or having anomalously large crystallite size are indicative of a nearby exhalative center. The data is consistent with the hypothesis that cherts record a thermal anomaly in the vicinity of sulfide deposition. In conclusion, the use of stable oxygen isotopes and crystallite size of cherts can be a potential exploration tool in the De Long Mountains and similar geologic areas for locating centers of submarine exhalation and possible associated mineralization.

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Introduction

The De Long Mountains are located north of the Arctic Circle, Alaska, at the western end of the Brooks Range (Fig. 1). Churkin et al. (1979) defined the Kagvik sequence in the western Brooks Range and traced it into the southeastern quadrant of the De Long Mountain Quadrangle where it is host to the Red Dog and Lik Pb-Zn sulfide deposits. Both the Red Dog and Lik deposits are submarine exhalatives associated with carbonaceous chert and siliceous shale horizons. Their discovery provided the impetus for much exploration within rocks of the Kagvik sequence which are predominantly marine cherts, argillites and shales.

Favorable chert horizons often cap syngenetic marine sulfide deposits in other districts and may be traced as marker beds in exploration for additional deposits, e.g. the "Key tuffite" of the Matagami Lake deposit (Roberts, 1975). In contrast, exploration for submarine exhalative deposits in the western De Long Mountains is made difficult by the repetition of chert lithologies throughout the Kagvik sequence, the lack of volcanics associated with the deposits and the complex structural history of the De Long Mountain area. Therefore, an exploration method is needed which discerns between those cherts favorable to mineralization and those for which little potential exists.

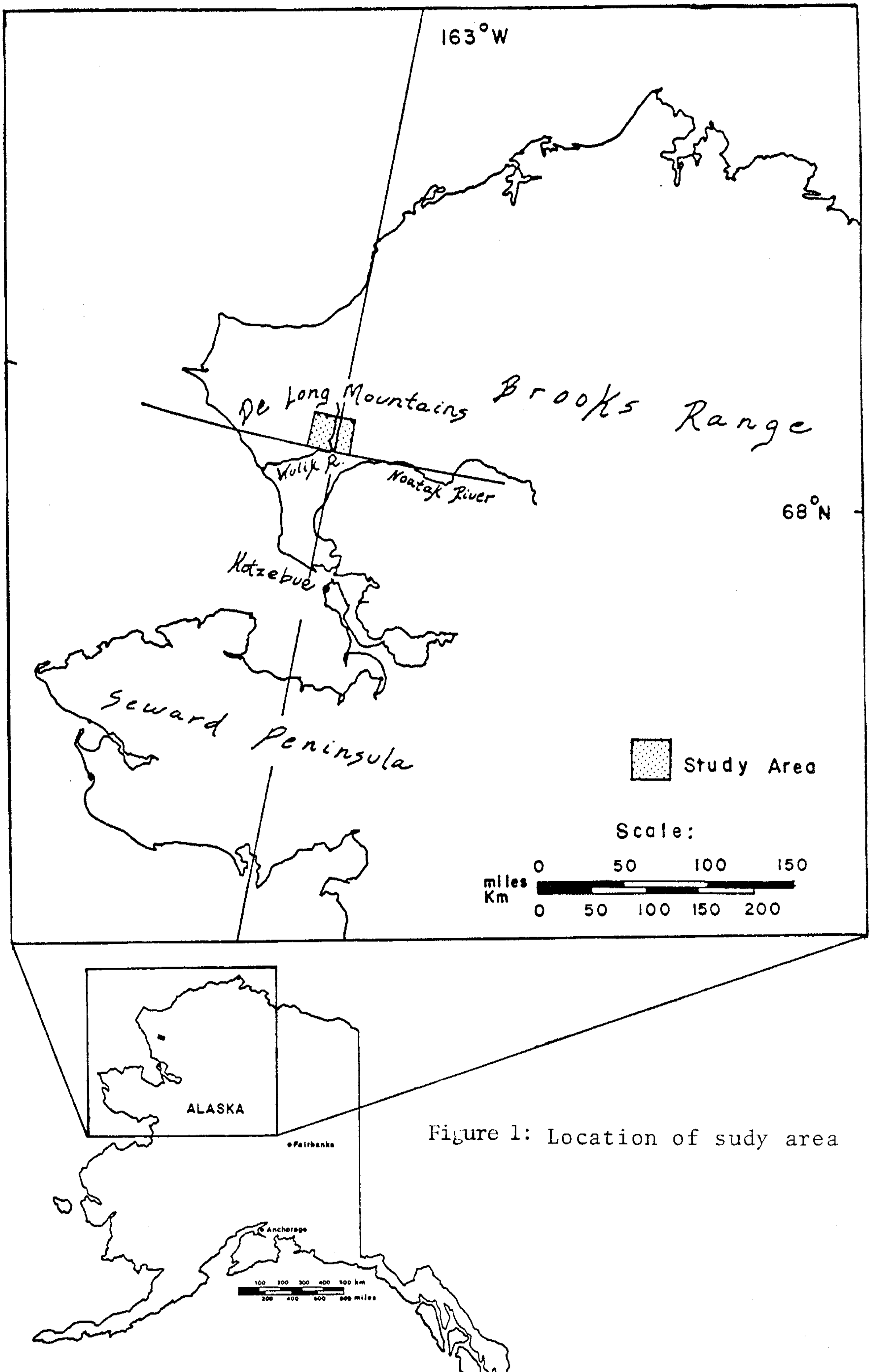

Figure 1: Location of sudy area

A mechanism for the formation of submarine exhalative deposits is possible if, as has been suggested by Metz (1980), the Kagvik sequence formed under conditions of rifting. Submarine rift conditions would provide circulating hot brines that could have introduced sulfides onto sea floor sediments. As a Consequence, the elevated temperatures associated with these hot brines would also have affected the surrounding sediments.

Since $\delta^{18}O$ and crystallite size of chert are temperature related, and since thermal activity is common about centers of submarine exhalation; cherts in the vicinity of the Red Dog and Lik deposits were studied to determine if $\delta^{18}O$ and/or crystallite size could be used as an exploration tool to indicate centers of submarine thermal activity.

The natural log of the fractionation factor for oxygen isotopes fractionated between silica (chert) and water is proportional to the inverse of the temperature squared for that system in which the silica crystallizes (Faure, 1977, p. 351). Therefore, the silica in a silica-seawater system undergoing increasing temperature will show a respective decrease in its $\delta^{18}O$ values (see Fig. 3, Clayton, O'Neil,and Mayeda, 1972).

Renault (1980) has demonstrated that crystallite size of chert is also temperature dependent. Crystallites are the submicroscopic ideal crystal blocks which group together to form crystals (Zachariasen, 1967). Each crystallite is a minute perfect crystal set off from other crystallites by imperfections or dislocations in the crystal lattice. As temperature increases, added surface free energy causes crystallites to grow larger by the "annealing out" of dislocations. The size of chert crystallites may be determined from line broadening or resolution of x-ray diffraction peaks (Renault, 1980; Iovenitti, 1977).

It was postulated that cherts experiencing elevated temperatures near centers of submarine exhalation should form larger crystallites and have lower $\delta^{18}O$ values than cherts crystallizing under normal sea floor conditions. Hence, $\delta^{18}O$ and crystallite size of cherts might be possible exploration guides for discovering exhalative-type deposits hosted by bedded cherts and argillites.

Geologic Setting

Regional Geologic Setting

The northwestern Brooks Range, of which the De Long Mountains are the very western part, is comprised of a complex, structurally deformed package of sedimentary rocks. As summarized by Tailleur (1970), a long period of marine sedimentation occurred from Devonian to Mississippian time. Marine carbonates were deposited in a broad basin with near shore clastic rocks interfingering from the north. From Permian through Jurassic time, minor sedimentation of marine shale, chert and limestone occurred in this basin. To the south, uplifted mafic volcanics and mafic to ultramafic intrusions, thought to be Jurassic in age, shed detritus northward. North-south compression during Cretaceous time caused thrusting, foreshortening and folding of the marine sediments and the igneous and volcanic rocks to the south. By late Cretaceous or early Tertiary time the Brooks Range had evolved to its present configuration.

Geologic Setting of Study Area

The study area is located near the southern flank of the De Long Mountains at the base of the Wulik Peaks. It lies within the De Long Mountain quadrangle maps, A-2 and

A-3. For references to previous work and detailed stratigraphic columns applicable to the study area, see Appendix I, pages 35-38.

A detailed geologic map for this area has not been published to date. It is, however, clear that two separate sequences in the De Long Mountains are juxtaposed due to the effect of thrusting and foreshortening (Churkin et al., 1979; and Tailleur, 1978). One, a shelf margin sequence, consists primarily of Paleozoic limestones which become more chert-rich higher in the section and finally grade into Permian to Triassic marine cherts and shales (Fig. 10, Appendix I, p.36). Coeval with deposition of this sequence, a basin sequence (consisting of carbonaceous black cherts and shales grading upward into interbedded cherts and shales) was deposited off the shelf margin to the south (Churkin et al., 1979). Volcanic and intrusive rocks are notably lacking in this locale, but do exist further south and to the east. There is some debate over the tectonic regime in which the sediments were deposited (Nokleberg and Churkin, 1980). There is agreement that the carbonaceous cherts and shales represent basin sedimentation whether that be in a back-arc basin (Churkin et al., 1979), an aulacogen (Metz, 1980), or local euxinic basins on the shelf itself (Tailleur, 1978). In any case, the carbonaceous horizons of this basin sequence host the sulfide mineralization in the study area (Tailleur, 1970).

Structure

The stratigraphic section exposed in the De Long Mountains was disrupted by numerous thrust faults and folds which occurred during the Cretaceous. The prominent ridge-former in the area is the Lisburne Group limestone of the shelf sequence which, in numerous thrust slices, unconformably overlies younger rocks of the shelf sequence and all rocks of the basin sequence. Tight folding occurs mainly in the less competent shales and cherts of the lower thrust sheets. Churkin et al. (1979) summarized the structural history as Cretaceous compression of a back-arc basin which began forming in Mississippian times. The compression resulted in foreshortening of this basin until its basin sediments were interleaved thus producing the Kagvik sequence. Sheets of the basin's shelf sediments were then thrust relatively southward to overlie the Kagvik sequence (see Fig. 1, Churkin et al., 1979). No matter what mechanism is called upon to cause the present day configuration, it nonetheless remains a highly complex sequence of rocks; and it is in the most complex part called the Kagvik sequence by Churkin et al. (1979) that sulfide mineralization occurs.

Known Sulfide Mineralization

Four sulfide occurrences were sampled: Red Dog, Lik, Ferric Creek and Hot Dog Creek with Red Dog and Lik being the major deposits.

There are two types of mineralization at Red Dog (Plahuta, 1977). Sulfide veins occur in locally silicified black shales and cherts. Stratiform mineralization overlying the vein deposits occurs in a siliceous and baritic unit interfingered with gray-green argillites and cherts. Based on dates obtained from radiolaria, Lange (1980) reported a Triassic age for mineralization at Red Dog.

Mineralization at Lik takes the form of stratiform massive sulfides, sulfide sediments and sulfide sediment breccias. The major difference from Red Dog is apparent absence of underlying vein deposits. Dates obtained from radiolaria in cherts closely associated with the Lik deposit indicate that the cherts formed in late Paleozoic, Triassic and even early Cretaceous time suggesting similar ages for mineralization. It is possible that thrusting or folding has interleaved sediments much younger than the age of mineralization, thought to be Mississippian, and that these thrusts or folds have not been noted. It is also possible that the ages assigned to the radiolaria may not be correct in this case. It would seem that a Mississippian to early Permian age for mineralization applies if the dark basin facies is coeval with deposition of the Paleozoic limestones of the shelf margin sequence. If, however, the dark basin facies spans time to become even younger in age than the Paleozoic limestones, this might help to explain some of the radiolarian dates.

At Ferric Creek, massive pyrite occurs in highly carbonaceous shales and cherts (Tailleur, 1970, p.9). There is no sphalerite or galena at this locale. At Hot Dog Creek, there is a small showing of fine-grained sphalerite, galena and pyrite in chert. Mineralization at Hot Dog Creek is predominantly stratiform and very much like that found at Lik.

Procedures

Fifty cherts covering the area around the four sulfide occurrences were collected from drill core and surface outcrop (Fig. 11, Appendix III, p. 49). Thin sections were made from each sample and the sample was then crushed. Vein quartz was removed by hand picking. Further preparation for $\delta^{18}O$ analysis involved grinding and sieving to obtain the 100 to 200 mesh size fraction; use of density methods to remove clays and heavy minerals; treating in both hydrochloric and nitric acid to remove other impurities; and heating overnight at 500°C to drive off organic compounds. Oxygen was extracted from the samples following the procedures described by Clayton and Mayeda (1963). Final $\delta^{18}O$ results are reported relative to SMOW. The procedures outlined by Renault (1980) were followed to determine the crystallite size of twenty cherts from line broadening of x-ray diffraction peaks. More specific details concerning sample preparation and analysis for both $\delta^{18}O$ and crystallite size are presented in Appendix II, pages 40-47.

Results

Petrographic analysis of the chert samples indicates that microcrystalline quartz (chert) occurs as an authigenic groundmass. Detrital quartz grains are minor, and when they are present, usually form less than 5% of the total quartz content. Chalcedony is sometimes found in spherulites and veinlets crosscutting the chert groundmass. Accessory phases are carbonate, black organic debris and clay. In addition, fine-grained pyrite, specular hematite, magnetite and manganese oxides occupy interstitial pore spaces and coat fractures. Barite, gypsum, quartz, chalcedony and black opaque minerals occur in minor amounts as vein infillings.

Detailed petrographic descriptions of the chert samples are reported in Appendix III, page 55. All samples collected in the field were, by rock description, either cherts or siliceous shales. Upon analysis in thin section, recognition of mineral constituents other than silica may have altered the petrographic name from the original rock name. Quartz, however, is always the greatest percentage of the total rock, except where obscured by organic debris in thin sections that are too thick or where there are also abundant sulfide minerals.

The chert samples have been divided into four lithologies on the basis of textural characteristics or dominant impurities. If the sample was visually estimated in thin section to contain $\geq$10% organic debris, then that sample, irregardless of other constituents, was considered to be carbonaceous chert (see Fig. 2). If the organic debris constituted less than 10% of the sample, but carbonate was present in amounts $\geq$10%, then that sample was considered to be calcareous chert (see Fig. 3). All other samples containing less than 10% of either organic debris or carbonate and greater than 90% quartz were categorized as varicolored cherts (see Fig. 4). "Varicolored" refers to the chert's black, red or green color depending upon the presence of manganese oxides, hematite or pyrite. The laminated/vuggy cherts are a separate category containing greater than 90% quartz and a laminated or vuggy texture (see Fig. 5). This type of chert is commonly found near the deposits, and is represented by only three samples, 57, 70 and 84.

Stable oxygen isotope results with their yields are presented for each sample with the sample's petrographic name in Table I, pages 50-52. Replications of $\delta^{18}O$ analyses were done for several cherts and these results are presented in Table II, page 53. In Figure 6, the $\delta^{18}O$ data is plotted for each chert versus the chert's lithology.

Figure 2 Sample # 225. Dark patches of organic debris infill interstitial spaces between grains of microcrystalline quartz. Crosscutting veinlet is infilled with chalcedony.

Figure 3 Sample #8. Rhombs of carbonate comprise greater than 10% of this sample. Carbonate is second only to the matrix of jigsaw puzzle quartz as a major mineral.

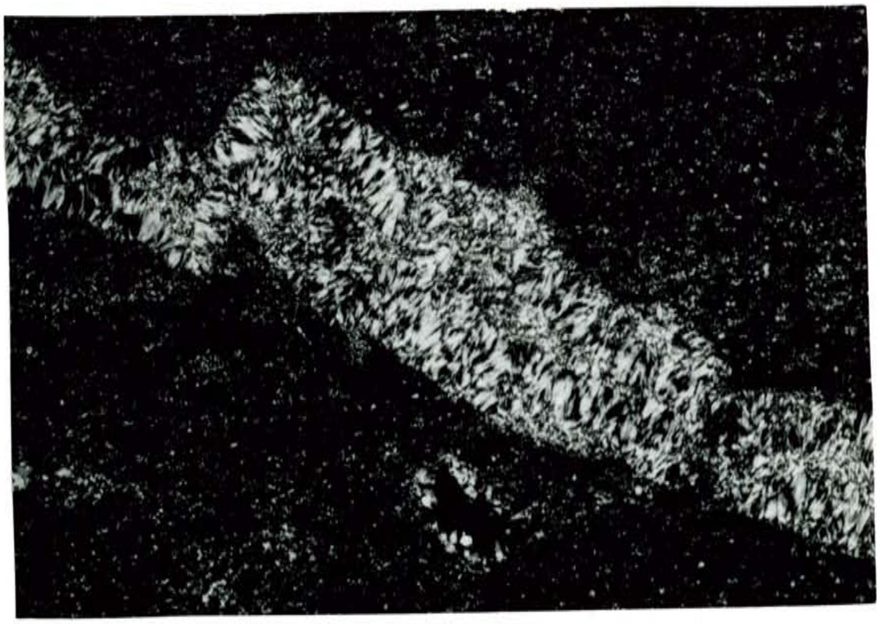

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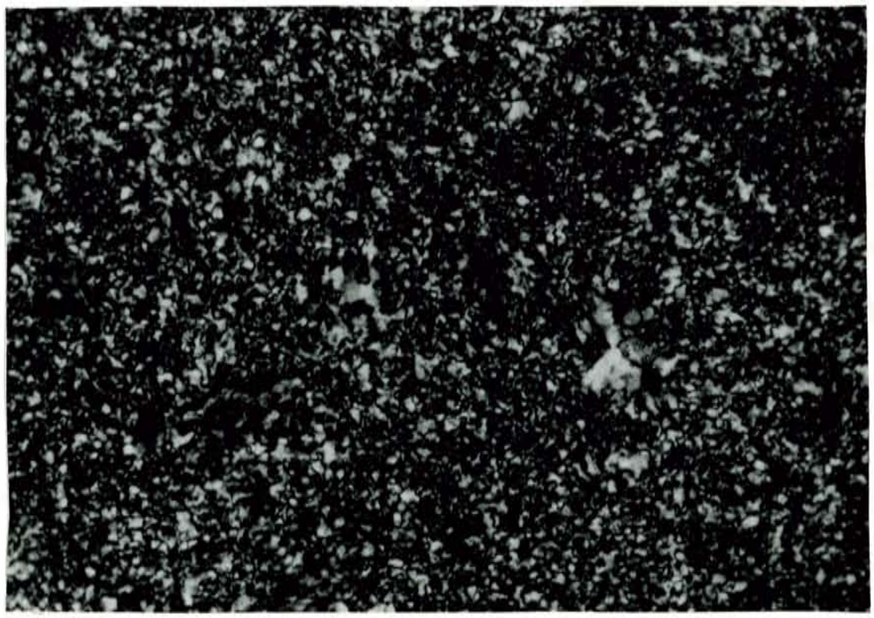
Figure 4 Sample #407. Sample is almost entirely chert and here is predominantly the textural variety-jigsaw puzzle quartz. Also, some disseminated opaque minerals occur in minor amounts.

Figure 5 Sample #57. Laminated/vuggy texture in chert is the result of alternating bands of different size quartz grains. Microcrystalline quartz forms the darker bands. Lighter bands are comprised predominantly of jigsaw puzzle quartz and can be vuggy as well. Also note some angular, possibly detrital, quartz grains along with quartz grains having typical chert textures.



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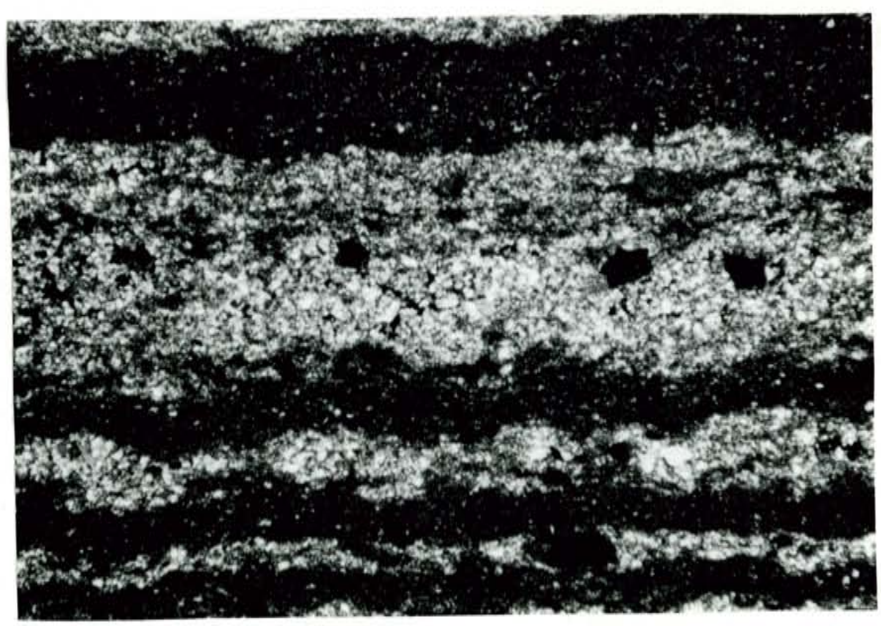

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There is a trend for cherts with oxygen isotope values in the 20‰-27‰ range. This trend is from lower to higher $\delta^{18}O$ values looking at carbonaceous to laminated/vuggy to calcareous to varicolored chert. The trend is the result of the lower $\delta^{18}O$ values for sulfide mineral associated cherts. If these were removed from the figure, no trend from lower to higher $\delta^{18}O$ values would be observed. At least a 4‰ spread in $\delta^{18}O$ exists for each type of chert, and these overlap one another. The largest spread in values (+20.7‰ to +30.9‰) occurs for the carbonaceous cherts which are the predominant host lithology for the sulfide deposits. Since no clustering of $\delta^{18}O$ values occurs and no convincing trend from low to high values is observed between lithologies, $\delta^{18}O$ does not distinguish between the lithologic varieties of chert. When an attempt was made to assign chert samples to presumed stratigraphic formation and then plot these relative to their $\delta^{18}O$ results, there was a similar spread in values and lack of trend from formation to formation. However, what can be said is that most of the cherts associated with mineral deposits have lower $\delta^{18}O$ values (+20‰ to +27‰) than do the cherts from nonmineralized localities (+27‰ to +32‰).

A plan view of the study area (Fig. 7) shows that the five samples with lowest $\delta^{18}O$ values are within one kilometer of known mineralization. At Red Dog, three samples of siliceous rocks which host mineralization yield

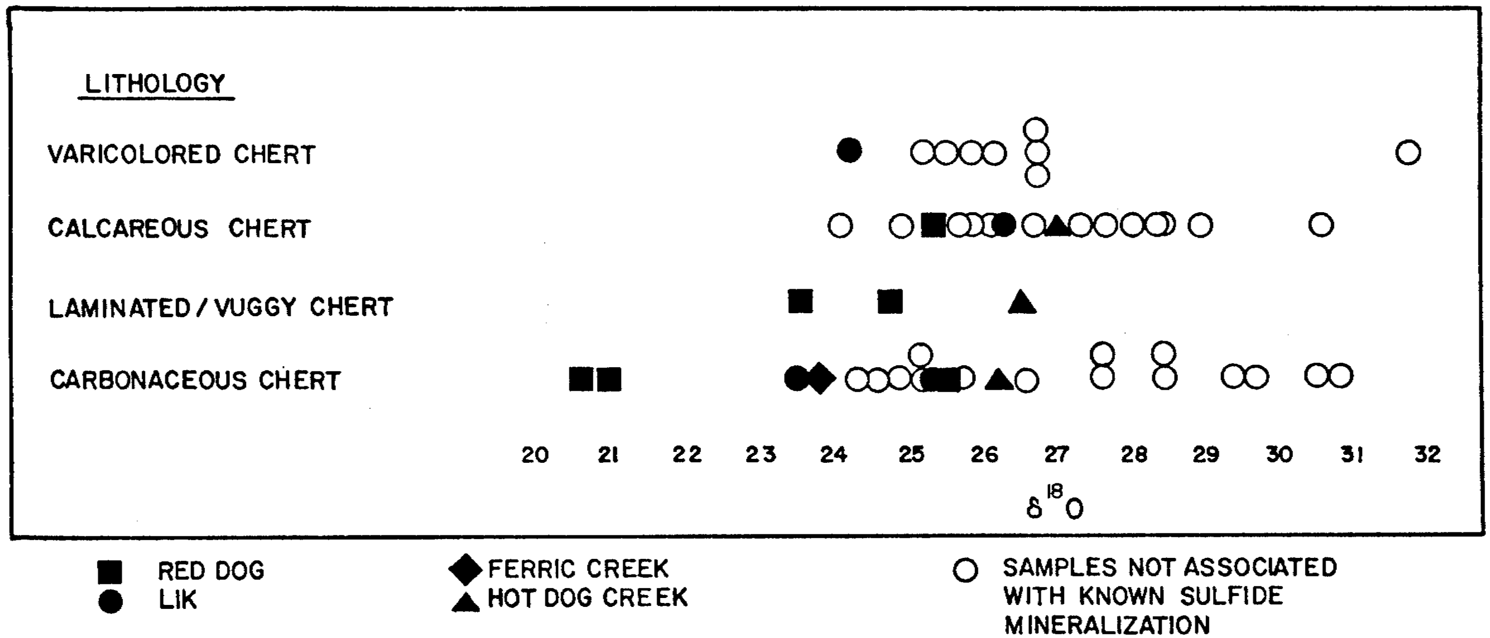

Figure 6: Stable oxygen isotope values versus lithology

$\delta^{18}O$ values: +20.7‰, +21.0‰, and +23.7‰. At Lik, a carbonaceous chert breccia below mineralization yields a $\delta^{18}O$ value of +23.7‰, and in the vicinity of Ferric Creek (Tailleur, 1970, p.9) a carbonaceous, pyritized chert yields a $\delta^{18}O$ value of +23.8‰. Not all samples near sulfide mineralization have low $\delta^{18}O$ values. Three samples each at Lik and Red Dog have intermediate $\delta^{18}O$ values. However, all samples with low $\delta^{18}O$ values (less than 24‰) are within one kilometer of known sulfide deposits.

Results of the crystallite size determinations are similarly represented in plan view (Fig. 8). The crystallite sizes and their calculated temperatures, using the silica crystallite geothermometer calibration equation of Renault (1980, p.7), are reported in Table III, page 54. Of the twenty samples analyzed, six have anomalously large crystallite sizes ($>$ 1300 Å). These are the same samples that had anomalously low $\delta^{18}O$ values at Red Dog, Lik and Ferric Creek. There is also one sample from Hot Dog Creek that has an intermediate $\delta^{18}O$ value, +26.3‰, but a large crystallite size, 1524 Å. In general, the crystallite sizes are larger for those samples with the lowest $\delta^{18}O$ values.

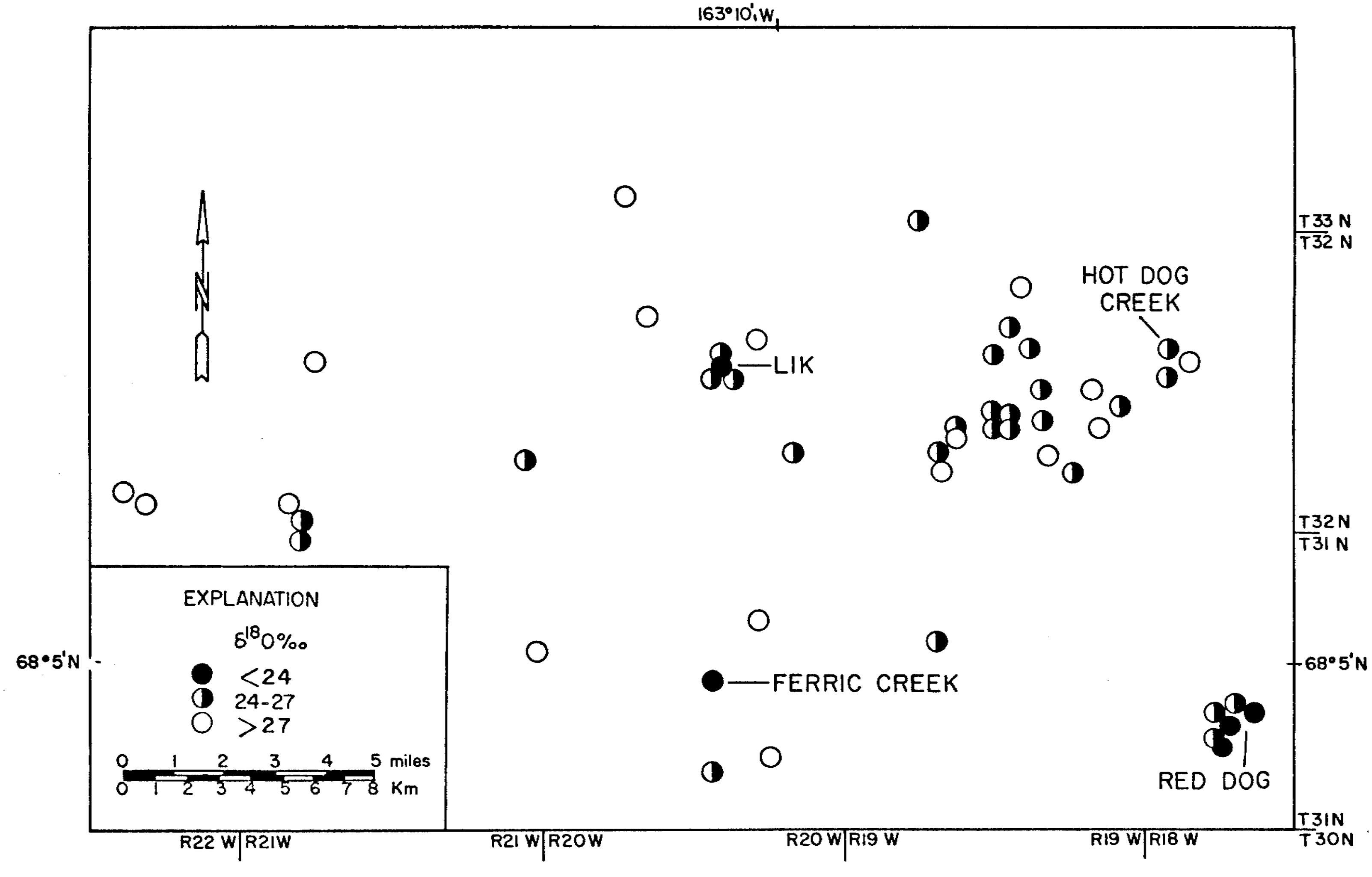

Figure 7: Stable oxygen isotope values of cherts and location of chert samples with respect to known sulfide deposits

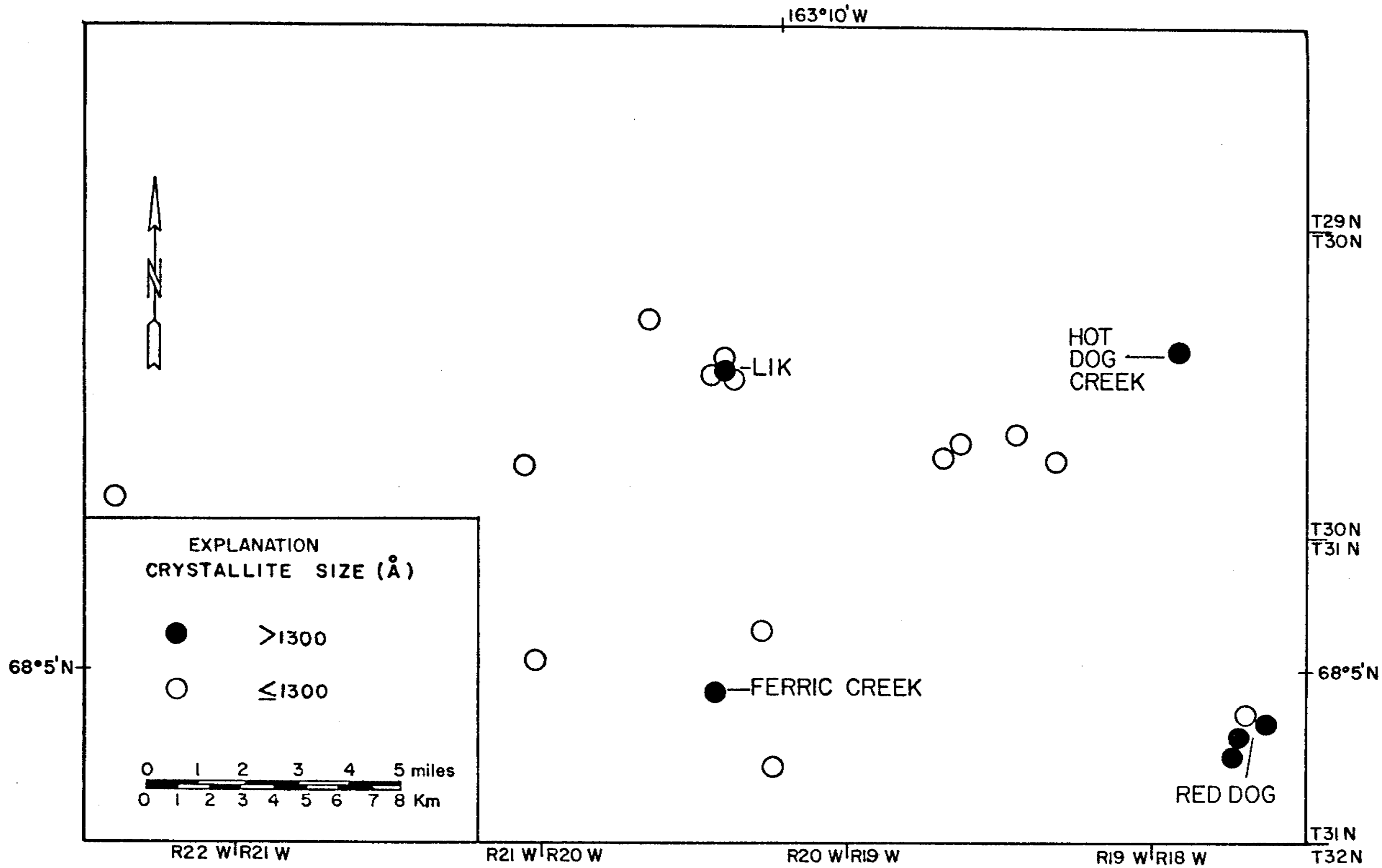

Figure 8: Crystallite size and location of chert samples with respect to known sulfide deposits

Discussion

Stable Oxygen Isotope analysis

The results indicate that both $\delta^{18}O$ and crystallite size reflect proximity to mineral deposition. As was expected, the $\delta^{18}O$ values are lower and the crystallite size is larger for cherts near mineralization than for surrounding cherts. This could indicate that higher temperatures were present near mineralization than were present in the surrounding areas. The exact temperatures relative to the $\delta^{18}O$ values cannot be calculated since the per mil value of the marine waters at the time of the formation of the chert is not exactly known. There is some discrepancy between various temperature/$\delta^{18}O$ calibration equations that have been proposed, especially at the low-temperature end. However, no matter which calibration equation is used or what per mil value is assumed for the water, the trend of warmer temperatures and lower $\delta^{18}O$ values for chert samples near mineral deposits remains.

The spread in $\delta^{18}O$ values for all the cherts contains values that are lower than expected for cherts which formed under marine conditions during Mississippian to early Cretaceous times. Knauth and Lowe (1979) attribute such spreads in $\delta^{18}O$ values for Precambrian cherts to post-depositional interaction with meteoric waters and elevated temperature during burial and diagenesis. These effects could have regionally altered the $\delta^{18}O$ values for the cherts after deposition, but it would be fortuitous for the greatest lowering of $\delta^{18}O$ to have occurred only about the sites of mineral deposition.

Metamorphism may also have an effect on the $\delta^{18}O$ values, but whether the resultant $\delta^{18}O$ value is decreased or increased depends upon the $\delta^{18}O$ value of the metamorphic fluids and the temperature involved (Knauth and Lowe, 1978). If metamorphism occurred under dry conditions, there would be little or no change in the original $\delta^{18}O$ value (Jones and Knauth, 1979).

Petrographic studies of the chert samples reveal no visible effects of metamorphism such as: recrystallization to megaquartz, triple point texture, or evidence of shearing (Jones and Knauth, 1979). In documented cases where metamorphism has had an effect on $\delta^{18}O$ of chert (Jones and Knauth, 1979; Knauth and Lowe, 1978), the samples usually show some type of metamorphic texture. Since metamorphic textures have not been observed in this study, metamorphism is considered to be of minor importance.

It would seem that some other process has determined the $\delta^{18}O$ values of cherts in the vicinity of the mineral deposits. Circulation of warm water may have continued during and after deposition of these cherts. It is quite possible that reaction with warm waters caused depletion of $\delta^{18}O$ in cherts already deposited and undergoing diagenesis; this could have produced the observed distribution of isotopic compositions.

Crystallite Size Analysis

The chert crystallite size data duplicates the same trends indicated by the $\delta^{18}O$ results. During or after deposition of the chert, interaction with warm water that may have caused low $\delta^{18}O$ values, could also have caused the chert crystallites to recrystallize and become enlarged.

Small initial crystallites deposited at temperatures of from 20°C to 50°C are approximately 30 Å in size (Fig. 2, Renault, 1980). Such small crystallites are not observed for the De Long Mountain cherts which have background values ranging from 500 Å to 1100 Å. Large background crystallite size is likely the result of regional burial and diagenesis. Under the influence of elevated temperatures caused by burial and diagenesis the small initial crystallites of the cherts are recrystallized and enlarged depending on the temperatures obtained.

The six chert samples that have crystallite sizes > 1300 Å, well above the background crystallite sizes, are also within one kilometer of the known sulfide deposits. These cherts have experienced much higher temperatures than those cherts sampled farther from the deposits. The higher temperatures were probably caused by thermal activity.

Thermal activity about centers of submarine exhalation caused initial enlargement of crystallite size beyond that obtained in the process of later burial and diagenesis. For this reason, these crystallite sizes are distinct from the background crystallite sizes for De Long mountain cherts.

An estimation of the temperatures involved in the processes of burial and diagenesis or hydrothermal activity may be calculated from the crystallite size calibration equation proposed by Renault (1980). This is a new technique which needs further refinement; however, the temperatures predicted are accurate to within $\pm$ 50°C for crystallite sizes < 3000 Å.

Crystallite size, temperature (using Renaults method) and $\delta^{18}O$ value are presented in Figure 9. For the cherts with anomalously large crystallite size, temperatures range from 270°C to 395°C. These are probably at least 50°C warmer than expected and could be due to discrepancies at the high-temperature end of Renault's calibration curve.

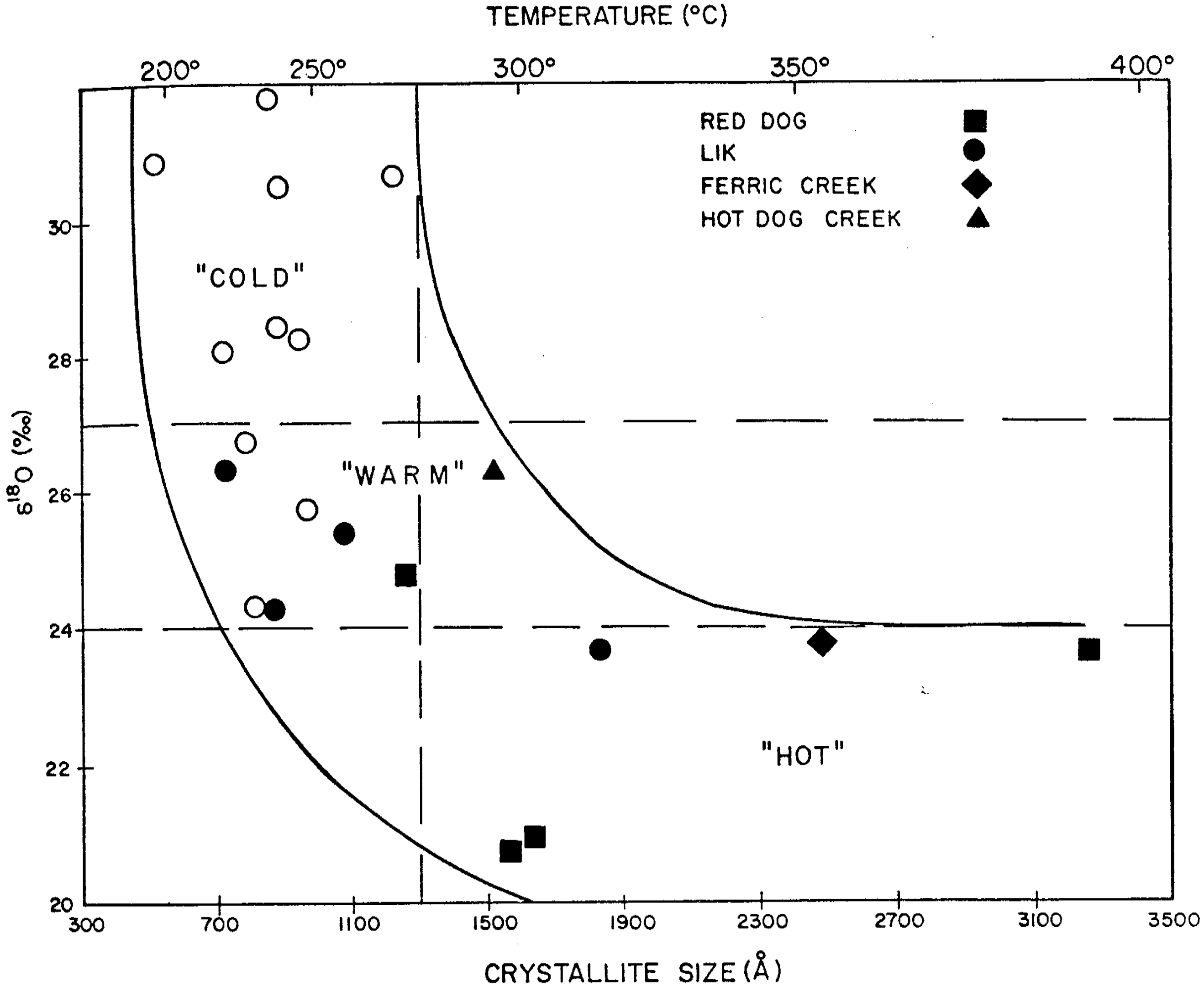

Figure 9: Stable oxygen isotope values versus crystallite size of chert. Temperatures calculated using the crystallite size geothermometer of Renault (1980).

Lange (1980) determined temperatures of 230°C to 270°C from s-isotope geothermometry for the Red Dog deposit. Although the tectonic regime of the study area is not exactly the same as that of the East Pacific Rise, the 380 ± 30°C temperatures reported by Speiss et al. (1980) for submarine exhalative activity along the rise indicates that such high temperatures can and do occur. In light of this fact, high temperatures of up to 270°C for thermal activity around the Red Dog deposit are reasonable values.

As with the $\delta^{18}O$ data, it is not the exact temperatures which are important, but the trend in crystallite sizes with respect to the location of sulfide deposits. Large crystallite size is observed for some cherts sampled within one kilometer of known deposits. Not all cherts within one kilometer of known deposits have large crystallite size; however, large crystallite size is a strong indication of a nearby submarine exhalative center.

Use As An Exploration Tool

Either $\delta^{18}O$ or crystallite size would be a useful tool exploring for sulfide deposits in the De Long Mountains. Oxygen isotopes could have indicated the presence of the Red Dog, Lik and Ferric Creek deposits. However, the $\delta^{18}O$ value for the Hot Dog Creek sample is in the intermediate range of values where, except for the large crystallite size, the presence of sulfides would have been difficult to detect. It is possible that vein quartz may have contaminated the sample, thus yielding the large crystallite size. If that were the case, the Hot Dog Creek sample would be more likely to lie in the region with the three samples from Lik and one from Red Dog which fail to indicate the presence of mineralization. It is important to note that not all cherts proximal to mineral deposits yield low $\delta^{18}O$ and large crystallite size. However, where anomalous values are noted for both $\delta^{18}O$ and crystallite size, the presence of submarine exhalative activity and possible associated sulfide deposits is strongly indicated.

In some respects, oxygen isotopic analysis is a difficult exploration tool. Oxygen isotope ratios of cherts may be affected by high percentages of impurities such as clays, or finely disseminated magnetite and hematite. In addition, the procedures are complicated, time-consuming and expensive. However, $\delta^{18}O$ may not be as susceptible as crystallite size to changes brought about by deep burial and diagenesis or metamorphism.

Crystallite size alone indicated the presence of all four deposits. Crystallite size analyses can be run on any chert sample which does not contain impurities that interfere with the quartz peaks. Crystallite size results should reflect the original temperature regime if the effect of subsequent metamorphism or burial and diagenesis has not masked them. Because of possible masking, the distal zones of deposits like Lik, which probably form at lower temperatures and therefore do not have such large crystallite sizes, may be difficult to detect by this method alone.

Summary

Oxygen isotopes and chert crystallite size were analyzed in the vicinity and surrounding areas of submarine exhalative deposits. The temperature-related parameters showed variation from average for cherts within one kilometer of known mineral deposits. This variation is in accordance with postulated high temperatures related to submarine exhalatives. Crystallite size analysis is the simplest and most direct means of detecting areas of paleo-submarine exhalative activity. However, its use may be precluded in areas which have undergone regional metamorphism. Stable oxygen isotope analysis is procedurally complicated, but can be more resistant to the effects of metamorphism. Therefore, in areas where regional metamorphism has occurred, the use of $\delta^{18}O$ analyses may be warranted.

Suggestions for Future Study

This study was intended either to eliminate the parameters, $\delta^{18}O$ and crystallite size, as exploration tools in the De Long Mountains or, the case here, to be the precursor to more in-depth studies of their viability. At this time, it is apparent that more work needs to be done in these areas:

> Detailed stratigraphic analysis needs to be made of units vertically above and laterally away from one deposit. These units should be carefully sampled and analysed for $\delta^{18}O$ and crystallite size to note variations with distance above and laterally away from the deposit. Ultimately this work would establish the size of an area around the deposit which might yield anomalous chert sample results for $\delta^{18}O$ and crystallite size.

> Advantage should be taken of presently active submarine exhalative areas. From careful sampling of the cherts in these areas a better idea of the actual temperature versus crystallite size calibration equation might be obtained. Changes of crystallite size with depth of burial and diagenesis might also be better established. Ultimately, this would provide a good model for the interpretation of results for paleo-submarine exhalative deposits.

> Finally, a similar study of both $\delta^{18}O$ and crystallite size should be conducted in a more highly metamorphosed terrain to establish just how effective these methods can be in areas which have undergone regional metamorphism.

Acknowledgments

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APPENDIX I

Previous Work and Stratigraphy Relating To The Study Area

APPENDIX I

Previous Work and Stratigraphy Relating To The Study Area

A definitive stratigraphic sequence applicable to the study area has not been worked out to date. An in-depth report on the formations west of the study area was done by Campbell (1967) and east of the study area by Churkin et al. (1978) and Nokleberg and Winkler (1978). The formations described in these reports have previously been established for the De Long Mountains.

Notably, the work of Sable and Dutro (1961) established the Mississippian Lisburne Group in the De Long Mountain area. The Permian through Triassic rocks of the Siksikpuk and Shublik formations were discussed at length for the Brooks Range in works by Patton and Tailleur (1964) and Chapman et al. (1964). They have been aptly described for the area just east of the De Long Mountain quadrangle by Churkin et al. (1979).

By way of summary, the stratigraphic columns of Figure 6 are presented as being applicable to the rocks found in De Long Mountain Quadrangles A-2 and A-3. There are two essentially time-equivalent sequences juxtaposed by

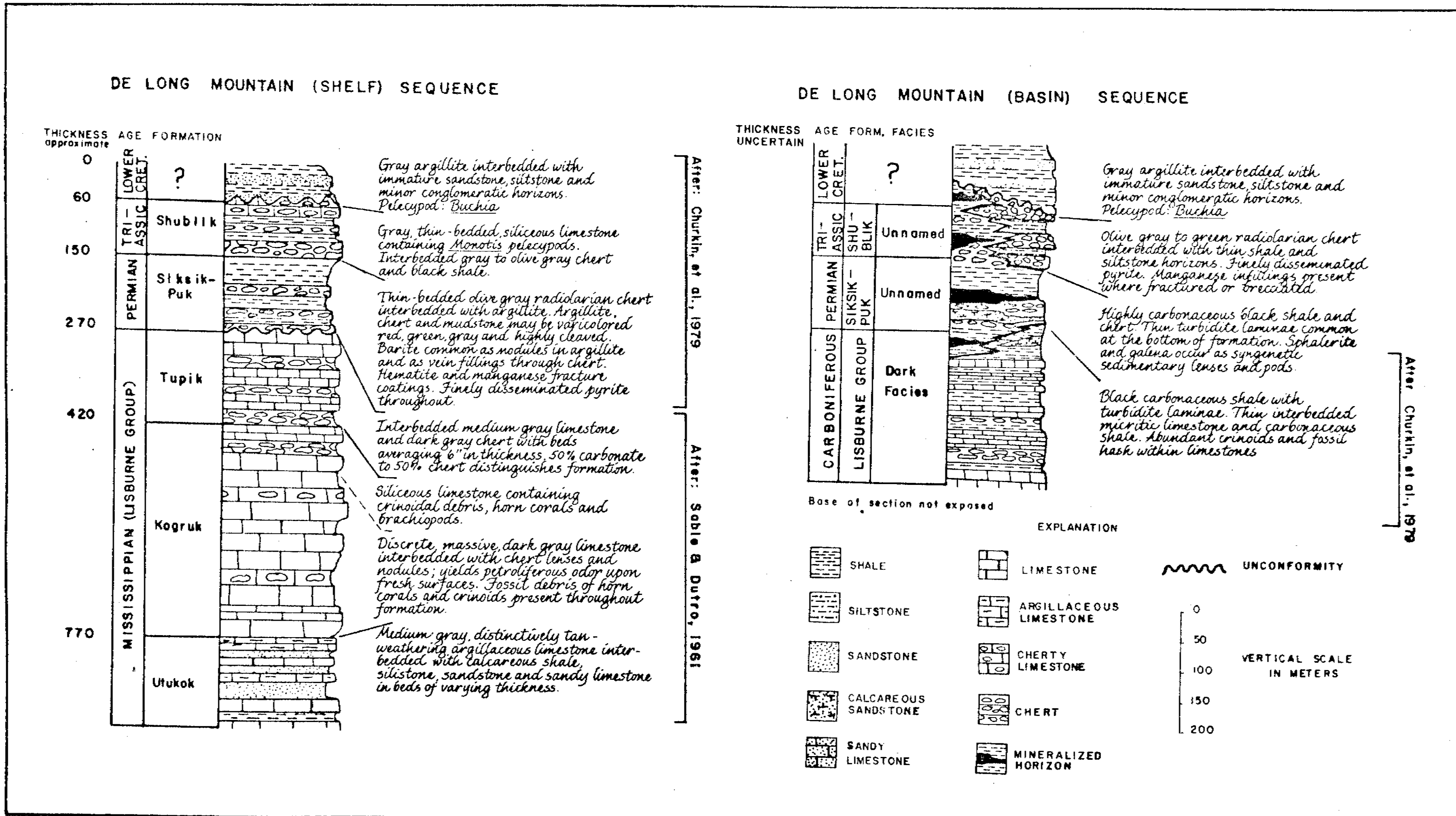

Figure 10: Stratigraphic Sequences

thrusting and foreshortening, as mentioned previously in the text, page 6. These are represented as De Long Mountain (shelf) and (basin) sequences.

The De Long Mountain (shelf) sequence is a composite of the descriptions by Sable and Dutro (1961) for Mississippian formations and the Permian through lower Cretaceous formations described by Churkin et al. (1979) for the Kagvik structural sequence. The thicknesses and characteristics of these formations are fairly well worked out. The time-equivalent basin sequence facies of these same formations are not well-established and their thicknesses, though not as great as the formations of the shelf sequence, are uncertain.

The basin equivalent of the Lisburne Group is documented by Tailleur (1970) as the dark facies and here by Churkin et al. (1979) as a carbonaceous unit of the Kagvik sequence. This unit is thought to be the host for the sulfide occurrences. This is the probable interpretation, placing the age of mineralization during Mississippian to early Permian times. However, radiolarian age dates indicate a Triassic age for the Red Dog deposit and a late Paleozoic or younger age for mineralization at Lik. Therefore, unnamed facies equivalents of the Siksikpuk and Shublik are presented as possible hosts to mineralization as well as late Paleozoic age rocks. These are described based on observations made by the author in the field and from core.

Due to Cretaceous compressional tectonics, the separate facies of these formations from either the shelf or basin sequence may be found in almost any configuration or juxtaposition - rendering it very difficult to unravel the stratigraphy and therefore to follow favorable chert horizons. In general, however, it is a sequence of carbonaceous shales and cherts with thin calcareous turbidite horizons that hosts the sulfide deposits.

APPENDIX II

I. Sample Preparation for $\delta^{18}O$ Analysis

II. Procedures Used in Oxygen Extraction

III. Calculation of Oxygen Isotope Ratios Relative to SMOW

IV. Sample Preparation for Crystallite Size Analysis

V. X-ray Diffraction Procedures Used for Measuring Crystallite Size

APPENDIX II

I. Sample Preparation for $\delta^{18}O$ Analysis

1. Select uniform chert from samples without macroscopically visible vein quartz or other impurities

2. Crush sample with Dia-Met mortar and pestle

3. Sieve sample to obtain the 100 to 200 mesh size fraction

4. Decante fine suspended particles from 20 cm column of water after three minutes settling time and again until water is clear

5. Separate heavy minerals (barite, galena, pyrite) using tetrabromoethane in separatory funnel

6. Heat in hydrochloric acid to remove calcite, magnetite and hematite

7. Heat in nitric acid to remove any remaining pyrite and galena

8. Heat overnight at 500°C to burn off organic compounds

APPENDIX II

II. Procedures Used in Oxygen Extraction

1. Weigh samples to .001 grams, each run having four samples and one Snowbird standard

2. Remove moisture from samples overnight in drybox

3. Load samples into evacuated vessels on the manifold in drybox and then replace the manifold on line - evacuate line

4. React samples overnight at 550°C to 600°C with bromine pentaflouride

5. Extract oxygen and react with heated carbon rods to form carbon dioxide

6. Measure sample over mercury manometer and calculate the percent yield

7. Freeze sample into pre-evacuated sample holder for later analysis on a mass spectrometer

III. Calculation of Oxygen Isotope Ratios Relative to SMOW

Results of oxygen isotope analysis of silica by mass spectrometer yeild the ratio of oxygen isotopes of the sample relative to a standard, Crestmore.

1. Correct $\delta\,{}^{\text{sample}}_{\text{crestmore}}$ for background and leakage

   and for tail: background and leakage averaged: 1.012
   tail = 1.004

2. Calculate $\delta\,{}^{\text{sample}}_{\text{smow}}$

EXAMPLE

To calculate $\delta\,{}^{\text{sample}}_{\text{smow}}$,

need to know $\delta\,{}^{\text{crestmore}}_{\text{smow}}$

Know: $\delta\,{}^{\text{snowbird}}_{\text{smow}} = +15.98$

Know: $\delta\,{}^{\text{snowbird}}_{\text{crestmore}}$:

SAMPLE	$\delta\,{}^{\text{snowbird}}_{\text{crestmore}}$
0 3 5 6 8 13 18 19 36 41 42 45 64 84 208 209 210 221 222 227	-12.06
24 46 50 53 69 211 212 225 228 230 231	-12.38
23 49 57 63 65 70 75 79 82 83 215 220 401 407 410 413 414 415 502	-12.27

$$\delta^{snb}_{cr} = \left[\frac{Rsnb}{Rcr} - 1\right] 1000; \quad Rcr = \frac{Rsnb}{\left[1 + \frac{\delta^{snb}_{cr}}{1000}\right]}$$

$$\delta^{snb}_{smow} = \left[\frac{Rsnb}{Rsmow} - 1\right] 1000; \quad Rsmow = \frac{Rsnb}{\left[1 + \frac{\delta^{snb}_{smow}}{1000}\right]}$$

$$\frac{Rcr}{Rsmow} = \frac{\dfrac{Rsnb}{\left[1 + \frac{\delta^{snb}_{cr}}{1000}\right]}}{\dfrac{Rsnb}{\left[1 + \frac{\delta^{snb}_{smow}}{1000}\right]}} = \frac{\left[1 + \frac{\delta^{snb}_{smow}}{1000}\right]}{\left[1 + \frac{\delta^{snb}_{cr}}{1000}\right]}$$

$$\delta^{snb}_{smow} = +15.98$$

$$\frac{Rcr}{Rsmow} = \frac{1.01598}{\left[1 + \frac{\delta^{snb}_{cr}}{1000}\right]}$$

δ^{snb}_{cr}	Rcr/Rsmow	δ^{cr}_{smow}
-12.06	1.02838	28.38
-12.38	1.02872	28.72
-12.27	1.02860	28.60

Have: δ^{smp}_{cr} , Want: δ^{smp}_{smow}

$$\delta^{smp}_{cr} = \left[\frac{Rsmp}{Rsmow} - 1\right] 1000; \quad \frac{Rsmp}{Rcr} = 1 + \frac{\delta^{smp}_{cr}}{1000}$$

$$\delta^{smp}_{smow} = \left[\frac{Rsmp}{Rsmow} - 1\right] 1000$$

$$\delta^{smp}_{smow} = \left[\frac{Rsmp}{Rcr} \cdot \frac{Rcr}{Rsmow} - 1\right] 1000$$

$$\delta^{smp}_{smow} = \left[1 + \frac{\delta^{smp}_{cr}}{1000} \cdot 1 + \frac{\delta^{cr}_{smow}}{1000} - 1 \right] 1000$$

$$\delta^{smp}_{smow} = \left[\delta^{cr}_{smow} + \delta^{smp}_{cr} + \frac{\delta^{smp}_{cr} \cdot \delta^{cr}_{smow}}{1000} \right]$$

EXAMPLE

$$\delta^{smp}_{smow} = \left[\delta^{smp}_{cr} + 28.38 + \frac{\delta^{smp}_{cr} \cdot 28.38}{1000} \right]$$

$$\delta^{smp}_{cr} \left[1 + \frac{28.38}{1000}\right]$$

$$\delta^{smp}_{smow} = 1.02838 \ \delta^{smp}_{cr} + 28.38$$

APPENDIX II

IV. Sample Preparation for Crystallite Size Analysis

1. Obtain split of chert sample
2. Crush to coarse sand size
3. Treat with hydrochloric acid to remove carbonate
4. Hand pick to remove any vein quartz material
5. Crush and sieve to pass 200 mesh screen
6. Wash with acetone to remove fine suspended particles of agate from mortar and pestle
7. Mount on slide using double stick tape covering only an area directly hit by x-ray beam, thus minimizing the amount of sample needed

APPENDIX II

V. X-Ray Diffraction Procedures Used for Measuring Crystallite Size

1. Scan a pure quartz sand standard (Ottawa sandstone) at a speed of 1/8° 2-theta/minute using 1/2° slits. Adjust x-ray beam to obtain optimum resolution

2. Scan silica peaks increasing 2-theta from 67° to 69°, and then decreasing 2-theta from 69° back to 67° 2-theta: first for the quartz standard and then each sample to be analyzed

3. Determine the resolution of the 212 $K_{\alpha 1}$ and $K_{\alpha 2}$ peaks for sample and standard using the equation:

$$R = \frac{100\ (P-V)}{(P-b)}$$

See Figure 4, Renault (1980)

4. Determine the ratio of intensities of the $212_{\alpha 1}/203_{\alpha 2}$ peaks for the standard and the sample. Using Fig. 5, Renault (1980), and taking the ratio of intensities into account, determine the broadening from the above calculated resolutions

5. Average the broadening from the scans of both standard and sample and use this value for further calculations

6. b is broadening of the standard (instrumental broadening) and B is broadening of the chert sample. Calculate b/B

7. Using Fig. 6 of Renault (1980), determine β/B where β is the pure diffraction broadening due to crystallite size of the chert sample. Calculate β :

$$\beta = B\ (\beta/B)$$

8. Using the Sherrer equation, crystallite size, D, is determined from β:

$$D = K\lambda / \beta \cos\theta$$

K is a constant taken as unity
λ is the wavelength of the x-radiation
θ is the Bragg angle

Using Cu radiation:

$$D = 88.4/\beta \cos\theta$$

9. Determine temperature using D in the silica crystallite geothermometer calibration equation:

$$T = 2940 / (12.5 - \ln D) - 273°C$$

(Eq. 3, Renault, 1980, p. 7)

APPENDIX III

Sample locations, Tables of Results and Petrographic Descriptions

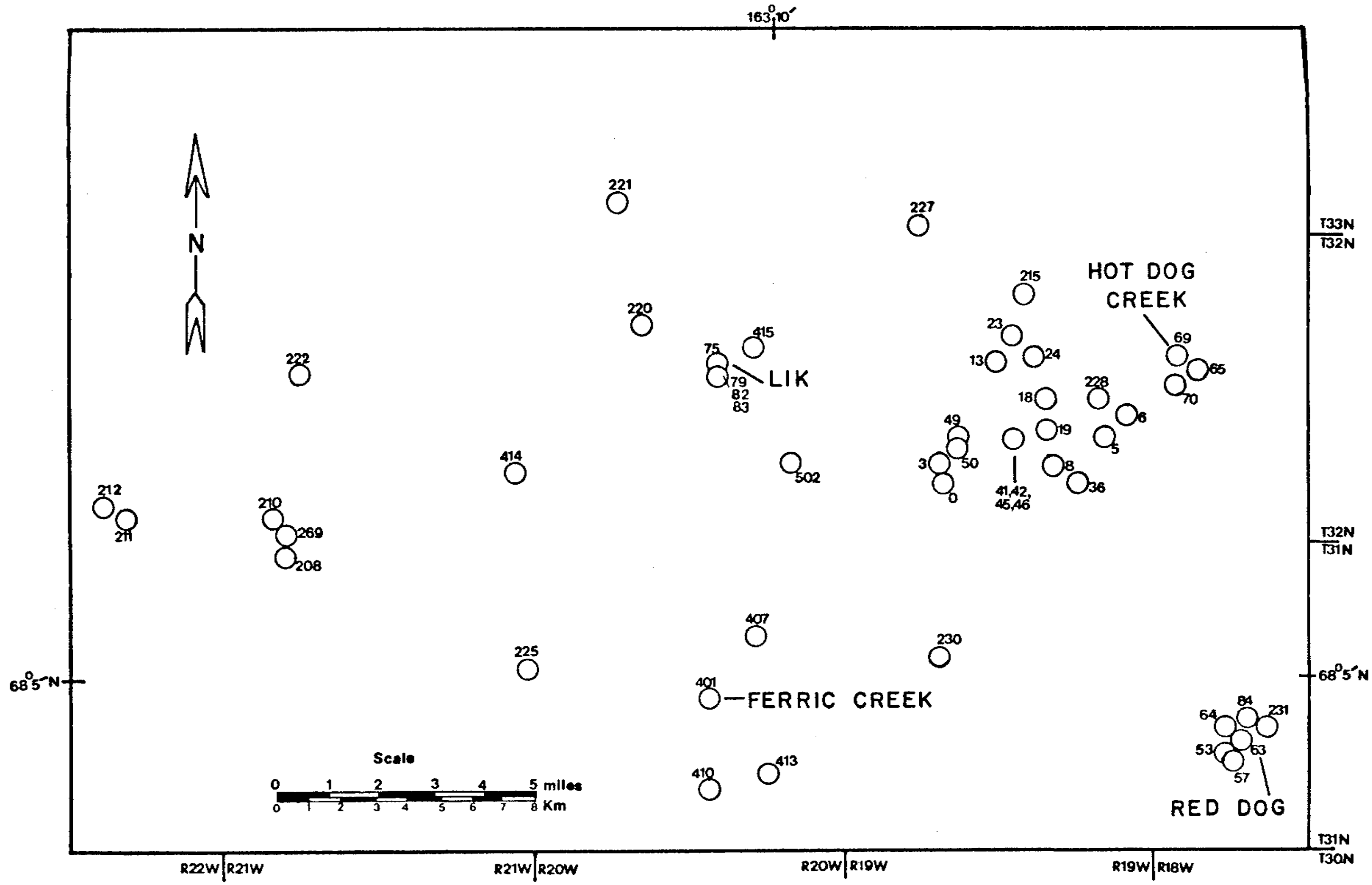

Figure 11: Sample numbers and locations with respect to known sulfide deposits

TABLE I

Stable Oxygen Isotope Results

Sample Number	$\delta^{18}O$	%Yield	Petrographic Name
0	28.6	79	Siliceous biolithite
3	26.8	88	Calcareous chert breccia
5	27.3	91	Chert
6	26.6	95	Carbonaceous, siliceous shale
8	30.7	94	Calcareous chert
13	24.9	91	Carbonaceous, siliceous shale
18	25.6	93	Carbonaceous, siliceous shale
19	25.9	90	Chert
23	25.4	89	Carbonaceous, siliceous shale
24	25.6	90	Chert
36	26.8	93	Chert
41	25.0	73	Calcareous chert
42	24.2	88	Carbonaceous, siliceous shale
45	24.7	79	Pyritic, carbonaceous, siliceous shale
46	24.4	87	Carbonaceous, Siliceous Shale
49	25.9	84	Chert biomicrite
50	28.5	77	Siliceous, algal biolithite
53	25.6	76	Carbonaceous, siliceous shale
57	23.7	93	Laminated chert
63	20.7	93	Carbonaceous, siliceous shale
64	25.5	92	Dolomitic chert
65	27.1	91	Calcareous chert

TABLE I (cont.)

Sample Number	$\delta^{18}O$	%Yield	Petrographic Name
69	26.3	95	Carbonaceous chert
70	26.0	92	Vuggy, laminated chert
75	26.4	86	Pelmicrite (?)
79	24.3	89	Micaceous, siliceous shale
82	25.4	92	Metaliferous, siliceous shale
83	23.7	90	Siliceous shale breccia
84	24.9	87	Silicified chert-shale breccia
208	26.2	79	Carbonaceous chert
209	26.2	89	Chert
210	27.6	90	Carbonaceous chert
211	29.0	94	Calcareous chert
212	28.1	93	Calcareous chert
215	28.4	88	Carbonaceous chert
220	30.5	92	Carbonaceous chert
221	29.4	98	Carbonaceous shale
222	29.7	95	Chert breccia
225	30.9	91	Carbonaceous chert
227	26.9	93	Chert
228	27.5	97	Carbonaceous chert
230	25.3	92	Carbonaceous chert
231	21.0	90	Carbonaceous, siliceous shale
401	23.8	95	Carbonaceous, siliceous shale
407	31.8	95	Chert
410	25.3	92	Micaceous, siliceous shale

TABLE I (cont.)

Sample Number	$\delta^{18}O$	%Yield	Petrographic Name
413	28.3	98	Calcareous chert breccia
414	25.8	94	Calcareous chert
415	27.7	92	Calcareous chert
502	26.8	92	Chert

TABLE II

Sample Replications of $\delta^{18}O$ Analyses

	Replication: $\delta^{18}O$				Replication: % Yield	
Sample no.	A	B	Diff.	Ave.Dev.	A	B
36	26.77	26.88	.03	26.8+/-.015	94	93
41	25.11	24.99	.12	25.1+/-.06	72.6	73
45	24.67	24.84	.27	24.8+/-.14	79.3	78.2
65	27.12	27.39	.27	27.3+/-.14	91.3	92.6
84	25.01	24.86	.25	24.9+/-.13	84.7	89.1
231	20.78	20.95	.17	20.9+/-.09	89.7	90.4
407	31.84	32.18	.34	32.0+/-.17	95.4	92.3

TABLE III

Crystallite Size and Temperature (*)

Sample Number	Crystallite Size (Å)	Temperature (°C)
3	799	233
8	1221	272
46	811	234
50	893	242
57	3274	395
63	1567	299
69	1524	292
75	737	225
79	874	240
82	1089	262
83	1842	317
84	1270	277
212	725	225
220	884	241
225	522	198
231	1637	303
401	2483	355
407	860	239
413	953	252
414	967	252

* Calculated using the silica crystallite geothermometer calibration equation of Renault (1980, p.7).

PETROGRAPHIC DESCRIPTIONS OF SAMPLES

SAMPLE NUMBER: 0 — COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray-green cherty limestone, weathers uniformly to tan. Monotis fossils along bedding planes appear as black streaks and crenulations. Upon weathering out, they give the rock a vuggy appearance across bedding. Some barite present in vugs.

ROCK NAME: Monotis chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Carbonate	69	.001 (mm)	Elongate, interlocking, anhedral crystals of calcite Monotis shells floating // to bedding in a micritic calcite cement.
Quartz	30	.02 (mm)	Fibrous chalcedony lining vugs and infilling remnant Monotis fossils. Jigsaw puzzle texture in quartz. Chalcedony and chalcedony spherulites recrystallizing to jigsaw puzzle quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	$\angle$1	.1 (mm)	Widely disseminated anhedral to euhedral crystals

PETROGRAPHIC NAME: siliceous biolithite

COMMENTS:

Limestone is undergoing silicification - quartz may be considered jasperoid. Widely spaced individual quartz crystals beginning to grow in micritic limestone, whereas some Monotis fossil fragments are almost entirely replaced by jigsaw puzzle quartz.

SAMPLE NUMBER: 3 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Black chert breccia fragments suspended in a matrix of limestone

ROCK NAME: calcareous chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	50	.05 (mm)	In chert fragments, note both jigsaw puzzle and granular quartz. Feathery quartz replacing chalcedony in spherulites. Granular quartz veins are crosscut by multiple generations of chalcedony & jigsaw puzzle quartz.
Carbonate	48	.12 (mm)	Blocky carbonate cement surrounding chert lithic fragments.

Accessory Minerals	%	Avg. Grain Size	Textures
Barite	1	.7 (mm)	Barite is found at boundaries between chert fragments and carbonate, and is being replaced by chert.
Pyrite	1	.03 (mm)	Euhedral crystals clustered in small zone where quartz is replacing carbonate.

PETROGRAPHIC NAME: calcareous chert breccia

COMMENTS:

This sample was taken from a small klippe of Tupik formation which has undergone intense deformation due to thrusting. This could explain the multiple quartz generations observed around fractures through chert lithic fragments.

SAMPLE NUMBER: 5 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Uniformly gray chert that weathers white and is commonly associated with immature sandstone.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	85	.015 (mm)	Uniform jigsaw puzzle quartz with grains varying from 5 to 20 microns. Some chalcedony infilling several veinlets.
Carbonate	13	.022 (mm)	Euhedral rhombs of carbonate, (possibly dolomite), dispersed in jigsaw puzzle quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Gypsum	∠ 1	.06 (mm)	Anhedral grains infilling fractures. Some grains show twinning and radial crystals.
Pyrite	∠ 1	.02 (mm)	Widely dispersed euhedral crystals.
Hematite & Unidentified opaques	∠ 1		Coatings on fracture surfaces

PETROGRAPHIC NAME: chert

COMMENTS:

SAMPLE NUMBER: 6 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Black chert with light-colored laminations that appear upon weathering.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	60	.005 (mm)	Jigsaw puzzle quartz throughout thin section, but grains become larger toward veinlets. Some widely dispersed terrigenous quartz grains. Original chalcedony spherulites completely recrystallized to jigsaw puzzle quartz.
Brown organics & clays	38	.003 (mm)	Small-grained matter could be clays showing fine laminations, 30 microns thick, that appear dark brown in plain light. Brown organic matter follows laminar texture, does not reflect light & shows no crystal structure.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	1	.003 (mm)	Widely disseminated anhedral to euhedral grains.
Hematite & Unidentified opaque	1		Occurs as fracture coatings and forms stylolites // to laminations.

PETROGRAPHIC NAME: siliceous carbonaceous shale

COMMENTS: In general, smaller crystalline quartz veinlets are older and offset by larger crystalline quartz veinlets. Small offsets for all veinlets occur across stylolites. Crystal size decreases from the center of veinlets outward. Possibly, silica-rich fluids early in the history of the rock were supplied through these veinlets and silicified an original carbonaceous shale.

SAMPLE NUMBER: 8 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Massive quartzose rock that appears to be recrystallized. Note dark to light-colored banding, cause uncertain.

ROCK NAME: laminated chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	70	.01 (mm)	Jigsaw puzzle quartz groundmass. Chalcedony spherulites being replaced by jigsaw puzzle quartz. Granular quartz infilling veins. Several generations of jigsaw puzzle quartz is evidenced by varying grain size from 5 to 30 microns.
Carbonate	28	.09 (mm)	Euhedral rhombs of carbonate dispersed in jigsaw puzzle quartz. Some may actually be siderite.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	1	.025 (mm)	Widely disseminated euhedral grains of pyrite found only in iron stained siliceous bands.
Hematite	<1		Hematitic staining occurs in bands throughout the thin section.
Unidentified opaque	<1		Black opaque mineral occurs as fracture infillings or as intergranular growths.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 13 **COLLECTED BY:** Robin Harrover

HAND SPECIMEN DESCRIPTION:

Carbonaceous chert with numerous crosscutting silica veinlets.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	70	.004 (mm)	Entirely jigsaw puzzle quartz. Numerous spherulites replaced by jigsaw puzzle quartz. A few veinlets infilled with granular quartz.
Brown organics & clay	20		May be some clay present with abundant brown organic matter.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	8	.015 (mm)	Euhedral carbonate rhombs pervasive throughout the thin section.
Mica	1	.006 x .02 (mm)	Acicular individual crystals widely dispersed throughout the thin section. Strong birefringence with n greater than balsam.
Pyrite	<1	.02 (mm)	Widely dispersed anhedral to euhedral crystals.
Unidentified opaque	<1		Fracture infillings. Forms stylolites and inter-crystalline amorphous growths.
Hematite	<1		Occurs predominantly as a stain.

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

SAMPLE NUMBER: 18 **COLLECTED BY:** Robin Harrover

HAND SPECIMEN DESCRIPTION:

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	70	.007 (mm)	Microcrystalline jigsaw puzzle quartz infilling spaces between brown organics and clay matter. Numerous cross-cutting veinlets infilled with granular quartz. Chalcedony spherulites being replaced by jigsaw puzzle quartz.
Clays & Organics	28		Forms a dense brown material in laminations surrounded by quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	<1	.008 (mm)	Widely disseminated anhedral to euhedral flakes and specks, probably authigenic in origin.
Unidentified opaque	<1		Black opaque infilling vainlets and occasionally occurring as interstitial material.
Hematite	<1		Forms a stain around fractures and oxidized pyrite

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

SAMPLE NUMBER: 19 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray-green chert interbedded with green, brown-weathering argillite.

ROCK NAME: gray-green chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	90	.003 (mm)	Almost entirely microcrystalline quartz. Grain size is so small that the texture is indiscernible. Some larger detrital quartz grains are present.

Accessory Minerals	%	Avg. Grain Size	Textures
Mica	10	.005 (mm)	Numerous elongate grains aligned // to depositional fabric.
Pyrite	<1	.016 (mm)	Widely disseminated anhedral to euhedral pyrite crystals
Hematite	<1		Hematitic staining along fractures.

PETROGRAPHIC NAME: chert

COMMENTS:

SAMPLE NUMBER: 23 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Carbonaceous, siliceous shale with chartreuse to rusty weathering fracture surfaces.

ROCK NAME: carbonaceous siliceous shale

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	80	.002 (mm)	Microcrystalline quartz. Grain size is too small to note texture. Granular quartz (.02 mm) infilling veinlets. Also, some minor detrital quartz grains.

Accessory Minerals	%	Avg. Grain Size	Textures
Brown organics & clays	10		Dense brown groundmass comprised of organic material and indeterminate clay minerals.
Pyrite	3	.05 (mm)	Anhedral, widely dispersed crystals. Uncertain if authigenic or detrital.
Mica	7	.002 x .015 (mm)	Detrital mineral with long axis // to sedimentary laminations.

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

SAMPLE NUMBER: 24 **COLLECTED BY:** Robin Harrover

HAND SPECIMEN DESCRIPTION:

Black chert: somewhat translucent, weathers to mottled colors of gray, green, pink and white.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	98	.02 (mm)	Predominantly jigsaw puzzle quartz, but some microcrystalline quartz that is so fine grained the texture cannot be discerned. Chalcedony spherulites being replaced by jigsaw puzzle quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	1	.008 (mm)	Euhedral crystals most abundant in one band, 1.5 mm wide. Euhedral form suggests pyrite is authigenic.
Unidentified opaque	< 1		Black opaque mineral infilling fractures.
Hematite	< 1		Occurs as a stain or infilling fractures within rock.

PETROGRAPHIC NAME: chert

COMMENTS:

SAMPLE NUMBER: 36 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray chert

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	90	.04 (mm)	Jigsaw puzzle quartz with fine-grained microcrystalline quartz less than .002 mm in size. Some granular quartz infilling veinlets. Relict chalcedony spherulites being replaced by jigsaw puzzle quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	9	.07 (mm)	Individual rhombs of carbonate, probably dolomite, interspersed within quartz groundmass.
Unidentified opaque	<1		Infilling fractures.
Hematite	<1		Red stain around fractures.

PETROGRAPHIC NAME: chert

COMMENTS:

SAMPLE NUMBER: 41 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray chert which occurs within a unit of red and green argillites.

ROCK NAME: calcareous gray chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	50	.002 (mm)	Fine-grained microcrystalline quartz. Individual crystals difficult to see. Also some granular quartz infilling veinlets and present as detrital grains.
Carbonate	40	.002 (mm)	Fine micritic limestone evenly dispersed throughout the thin section.

Accessory Minerals	%	Avg. Grain Size	Textures
Clays	6		Minor clays interspersed with micritic limestone throughout the thin section.
Mica	3	.005 (mm)	Fine-grained laths distributed in a random pattern to bedding, therefore could be authigenic.
Marcasite	1	.15 (mm)	Marcasite roses averaging .15 mm.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 42 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray-green chert breccia with fractures and intergranular space infilled with black opaque minerals. Disseminated pyrite crystals occur throughout the rock.

ROCK NAME: chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	70	.002 (mm)	Fine-grained microcrystalline quartz. Numerous small veinlets lined with granular quartz .05 mm in size. One larger veinlet infilled with quartz & carbonate. Also some detrital quartz grains present.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	10	.2 (mm)	Carbonate occurs as an evenly dispersed or as individual irregularly shaped grains being replaced by quartz.
Mica	10	.002 x .01 (mm)	Preferential alignment of grains with detrital layers. May vary from breccia fragment to breccia fragment. Some grains that are not aligned could be authigenic.
Unidentified opaque	8		Black opaque infilling numerous fractures, veinlets and spaces between breccia fragments.
Hematite	1		Hematitic stain around fractures.
Pyrite	1		Occurs with hematite infilling fractures and disseminated through breccia fragments.

PETROGRAPHIC NAME: calcareous siliceous shale

COMMENTS:

After the chert lithified, it fractured. Some of the fractured clasts were then ripped up and redeposited with interstitial space being infilled by quartz, black opaques and pyrite. See both rotated and non-rotated clasts as evidenced by mica flake orientations.

SAMPLE NUMBER: 45 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Highly carbonaceous chert with abundant disseminated pyrite grains

ROCK NAME: pyritic carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	30	.025 (mm)	Predominantly detrital quartz grains (20%), but also some microcrystalline quartz. Detrital quartz is subangular and poorly sorted.
Carbonate	30	.015 (mm)	Carbonate occurs as individual grains, approximately the same size as the detrital quartz grains. The grains are anhedral and subrounded.
Brown organics & clays	15		Brown organic material - possibly some minor clays present.

Accessory Minerals	%	Avg. Grain Size	Textures
Mica	10	.003 x .02 (mm)	Alignment of micas // to depositional laminations indicates they are probably detrital. Micas are evenly dispersed throughout the thin section.
Pyrite	10	.015 (mm)	Pyrite is abundant as subrounded detrital particles, and is common along stylolitic partings.
Unidentified opaque	5		Abundant along stylolitic partings.

PETROGRAPHIC NAME: pyritic, carbonaceous, siliceous shale

COMMENTS:

SAMPLE NUMBER: 45 continued COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

(Individual horizon within siliceous black shale)

ROCK NAME: calcareous arenite

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Carbonate	40	.1 (mm)	Grains of blocky calcite form the cement for the widely dispersed quartz grains. Also several calcite veinlets .2 mm - 1 mm wide.
Quartz	30	.1 (mm)	Angular grains range in size from .01 mm to .15 mm. Also, about 5% of total quartz is chert lithic fragments.
Pyrite	28	.05 (mm)	Pyrite occurs as clusters and dispersed euhedral to anhedral grains. Could be subrounded due to transport and weathering.

Accessory Minerals	%	Avg. Grain Size	Textures
Hematite	1		Interstitial hematitic staining.
Mica	1	.02 (mm)	Widely dispersed, randomly oriented flakes.

PETROGRAPHIC NAME: pyritic calcarenite

COMMENTS:

In hand specimen these horizons often show graded bedding and could represent thin turbidites. Sample taken from chert horizon overlying mineralization.

SAMPLE NUMBER: 46 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Carbonaceous chert

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	50	.025 (mm)	Terrigenous grains are subangular and comprise 25% of the total quartz. The remainder is microcrystalline quartz (.002 mm in diameter).
Carbonate	20	.025 (mm)	Individual subrounded grains scattered throughout the thin section.
Mica	15	.005 x .025 (mm)	Widely dispersed grains aligned // to depositional laminations.

Accessory Minerals	%	Avg. Grain Size	Textures
Organics & clays	10		Brown matrix of organic debris and clay.
Pyrite	4	.05 (mm)	Widely dispersed euhedral to anhedral crystals
Unidentified opaque	1		Forms numerous stylolites

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

Sample taken from chert horizon underlying sulfide mineralization.

SAMPLE NUMBER: 49 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray-green baritic chert with both finely disseminated and larger blebs of pyrite.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Carbonate	50	.035 (mm)	Micrite present throughout thin section. Some larger calcite crystals in the form of fossil fragments commonly being replaced by jigsaw puzzle quartz.
Quartz	40	.025 (mm)	Quartz forming jigsaw puzzle texture and replacing carbonate and fossils.

Accessory Minerals	%	Avg. Grain Size	Textures
Mica	5	.008 x .03 (mm)	Elongate crystals aligned parallel to depositional laminations.
Pyrite	4	.02 (mm)	Euhedral widely dispersed authigenic crystals.
Hematite	1		Occurs as a stain along fracture surfaces.

PETROGRAPHIC NAME: chert biomicrite

COMMENTS:

SAMPLE NUMBER: 50 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Highly carbonaceous siliceous shale which is also calcareous upon partings.

ROCK NAME: carbonaceous siliceous shale

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Carbonate	45		Micritic limestone compressed and crenulated to laminae and occasionally recrystalli ed to blocky calcite. Carbonate may be replaced by jigsaw puzzle quartz.
Brown organics	40		Opaque brown organic material that is interlaminated with the carbonate.
Quartz	14	.02 (mm)	Quartz forms jigsaw puzzle texture and infills pore spaces in both the organic debris and the carbonate. May be replacing carbonate. Also widely scattered terrigenous quartz grains.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	1	.005 (mm)	Widely dispersed crystals that do not follow sedimentary laminae or structures. Could be authigenic.

PETROGRAPHIC NAME: siliceous algal biolithite

COMMENTS:

SAMPLE NUMBER: 53 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Highly carbonaceous siliceous shale

ROCK NAME: carbonaceous siliceous shale

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	50	.003 (mm) & .035 (mm)	Microcrystalline quartz groundmass. Angular quartz grains form 20% of total quartz and are probably of terrigenous origin. Granular quartz infilling veinlets.
Carbonate	30	.005 (mm)	Abundant carbonate rhombs, probably dolomite, and some subrounded carbonate grains of terrigenous origin.
Brown organics & clays	14		Brown organics and possibly clays occur in crude laminations.

Accessory Minerals	%	Avg. Grain Size	Textures
Mica	5	.003 x .015 (mm)	Occurs as randomly oriented elongate grains.
Pyrite	1	.0065 (mm)	Widely dispersed crystals that do not follow sedimentary laminae.
Unidentified opaque	1		Black opaque infilling pore spaces and interstitial grain boundaries

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

SAMPLE NUMBER: 57 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Very finely laminated chert with interlaminated bands of black and white chert. Textures are similar to those which occur with banded sulfide mineralization at Lik.

ROCK NAME: laminated chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	97	.025 (mm)	Microcrystalline quartz forms more dense and darker laminations which alternate with jigsaw puzzle quartz laminations gradational into granular quartz. Also some terrigenous quartz grains in microcrystalline quartz laminae.
Mica	2	.003 x .015 (mm)	Mica flakes are roughly oriented // to bedding within the microcrystalline quartz laminae.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	<1	.004 (mm)	Widely dispersed minute grains, sometimes concentrated in interstitial spaces.
Unidentified opaque	<1		Dense black opaque occurs in interstitial spaces between grains.
Hematite	<1		Occurs as a stain on the laminations of microcrystalline quartz.

PETROGRAPHIC NAME: laminated chert

COMMENTS:

SAMPLE NUMBER: 63 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Very highly carbonaceous silicified shale

ROCK NAME: carbonaceous siliceous shale

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	80	.005 (mm)	Microcrystalline quartz groundmass. In places appears to be replaced by reticulate textured quartz. Granular quartz infilling veinlets. Terrigenous quartz grains, subrounded, comprises 10% of total quartz content.
Brown Organics	16		Forms crude laminations with no internal structures or textures evident within laminations.

Accessory Minerals	%	Avg. Grain Size	Textures
Micas	3	.003 x .02 (mm)	Widely distributed elongate grains that show no regular orientation.
Pyrite	1	.01 (mm)	Finely disseminated, evenly dispersed grains.
Unidentified opaque	1		Black opaque mineral concentrated along bedding planes.

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

Sample taken from siliceous shale just overlying mineralization at Red Dog.

SAMPLE NUMBER: 64 **COLLECTED BY:** Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray-green chert: weathers white, fractures conchoidally

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	83	.003 & .016 (mm)	Microcrystalline quartz groundmass. Relict spherulites and pore spaces completely infilled with jigsaw puzzle quartz. Granular quartz infilling veinlets

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	10	.04 (mm)	Rhombs of carbonate, probably dolomite, widely scattered throughout quartz groundmass. Also some calcite grains infilling veinlets.
Hematite	3		Hematitic stain common along fracture surfaces and oxidized pyrite crystals.
Pyrite	2	.02 (mm)	Widely dispersed euhedral octahedrons of pyrite.
Unidentified mineral	2	.01 x .05 (mm)	Bladed crystals of an unidentified mineral with low relief and low birefringence (first order grays) aligned // to bedding.

PETROGRAPHIC NAME: dolomitic chert

COMMENTS:

SAMPLE NUMBER: 65 **COLLECTED BY:** Robin Harrover

HAND SPECIMEN DESCRIPTION:

Homogeneous green chert

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	80	.015 (mm)	Jigsaw puzzle quartz. Relict spherulites replaced by jigsaw puzzle quartz. Large proportion of quartz is microcrystalline with minute carbonate inclusions scattered throughout.
Carbonate	15	.035 (mm)	Occurs both as widely dispersed rhombs and as micrite. Some small micrite inclusions within quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Gypsum	3	.05 x .09 (mm)	Elongate and radiating crystals infilling veinlets and fractures.
Pyrite	2	.015 (mm)	Widely dispersed euhedral crystals of pyrite.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 69 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Carbonaceous black chert with rusty-weathering fracture surfaces and widely disseminated galena crystals.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	85	.005 & .015 (mm)	Microcrystalline quartz groundmass with jigsaw puzzle quartz infilling pore spaces. Granular quartz infilling veinlets.
Carbonate	13	.055 (mm)	Widely dispersed carbonate rhombs, probably dolomite. Also occurs as fine grained inclusions within quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Hematite	1		Hematitic staining along fractures and veinlets - also present around oxidized pyrite.
Pyrite	1	.02 (mm)	Widely dispersed anhedral grains.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

Mix-up in thin sections. Thin section is not of the same rock as the hand sample. Hand sample is carbonaceous chert and was the sample for which $\delta^{18}O$ and crystallite size was analysed.

SAMPLE NUMBER: 70 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Massive, vuggy, siliceous rock with fine laminations of alternating light gray to white quartz.

ROCK NAME: Vuggy, laminated quartz

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	99	.017 & .2 (mm)	Jigsaw puzzle quartz. Numerous vugs. Some pore space infilled with late stage granular quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Unidentified opaque	1		Interstitial black opaque mineral infilling space between grains.

PETROGRAPHIC NAME: vuggy laminated chert

COMMENTS:

Sample overlies mineralization in Hot Dog Creek.

SAMPLE NUMBER: 75 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray-green chert with conchoidal fracture

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Carbonate	95	.003 (mm)	Uniform micritic limestone with numerous elipsoid carbonate particles suggestive of fecal pellets.

Accessory Minerals	%	Avg. Grain Size	Textures
Quartz	5	.02 (mm)	Occassional terrigenous quartz grains or chert lithic fragments.

PETROGRAPHIC NAME: pelmicrite

COMMENTS:

Sample overlies mineralization at Lik.

SAMPLE NUMBER: 79 **COLLECTED BY:** Robin Harrover

HAND SPECIMEN DESCRIPTION:

Light gray chert clasts in a matrix of carbonaceous siliceous shale. Both blebs of pyrite and disseminated pyrite present throughout the rock. Chert clasts tend to be fractured and brecciated within themselves.

ROCK NAME: chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	70	.003 & .02 (mm)	Microcrystalline quartz, too small-grained to note textures. Also some subangular detrital quartz. Granular quartz infilling veinlets.
Mica	24	.003 x .015 (mm)	Abundant elongate flakes which tend to be aligned, but the rock is fractured and folded which has affected the direction of alignment so that original bedding is obscured.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	2	.035 (mm)	Abundant widely disseminated euhedral pyrite crystals. Around fractured areas, crystals tend to form in clusters.
Unidentified opaque	2		Forms black opaque coating along fracture surfaces and surrounding chert fragments.
Carbonate	1	.2 (mm)	Infilling veinlets with blocky carbonate.
Hematite	1		Hematitic staining along fractures and veinlets.

PETROGRAPHIC NAME: micaceous siliceous shale

COMMENTS:

Sample directly underlies mineralization at Lik.

SAMPLE NUMBER: 82 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Laminations of pyrite, sphalerite and galena through grey chert.

ROCK NAME: metaliferous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Pyrite	35	.08 (mm)	Abundant pyrite as coalescing bands of crystals or as massive pyrite laminae.
Quartz	25	.035 & .15 (mm)	Predominantly jigsaw puzzle quartz with granular quartz infilling pore spaces and veinlets. Minor terrigenous quartz within laminae of brown organic material and mica flakes.
Brown organics	20		Dense brown organic material forms laminations interbedded with pyrite, sphalerite and quartz.
Sphalerite	17	.2 (mm)	Predominantly individual euhedral to anhedral grains floating in a groundmass of brown organics or quartz. Also individual crystals included in massive pyrite and minute crystals coalescing to form a sphalerite lutite.

Accessory Minerals	%	Avg. Grain Size	Textures
Mica	3	.002 x .025 (mm)	Widely dispersed elongate mica grains occur associated with laminations of brown organics aligned roughly // to bedding.

PETROGRAPHIC NAME: metaliferous siliceous shale

COMMENTS:

Sample taken from within the mineralized horizon at Lik.

SAMPLE NUMBER: 83 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Gray to black chert crosscut by numerous quartz veinlets.

ROCK NAME: chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	70	.01 & .1 (mm)	Predominantly jigsaw puzzle quartz in large clasts, but numerous network veins are filled with granular quartz and this comprises 50% of the total quartz content.
Carbonate	15	.05 (mm)	Coalescing carbonate rhombs concentrated within the organic material and jigsaw puzzle quartz.
Brown organics & clays	11		Groundmass of brown organics and possibly minor clays form crude laminations with jigsaw puzzle quartz infilling pore spaces. Dolomite rhombs throughout.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	2	.02 (mm)	Several individual anhedral to euhedral crystals.
Unidentified opaque	2		Black opaque mineral infilling interstitial space between grains and also infilling pore space in quartz veins.

PETROGRAPHIC NAME: siliceous shale breccia

COMMENTS:

Sample taken from below mineralization at Lik.

SAMPLE NUMBER: 84 COLLECTED BY: Robin Harrover

HAND SPECIMEN DESCRIPTION:

Vuggy gray chert. Angular chert clasts in a matrix of light gray chert with numerous pore spaces throughout the rock.

ROCK NAME: chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	80	.01 & .6 (mm)	Groundmass of jigsaw puzzle quartz. Also granular quartz in numerous veinlets. Silicified clasts of jigsaw puzzle quartz leave only a relict film of brown organic matter over the original lithic fragment. Several clasts of microcrystalline quartz with terrigenous subrounded quartz grains widely dispersed throughout the thin section.

Accessory Minerals	%	Avg. Grain Size	Textures
Brown organics & clays	10		A thin film of brown organics and possibly some clays remain outlining what were shale clasts that have now become almost completely silicified by jigsaw puzzle quartz.
Apatite	7	.025 x .2 (mm)	Elongate crystals of apatite presently associated with granular quartz.
Unidentified opaque	2		Occurs as a black opaque mineral infilling interstitial space between grains.
Hematite	1		Minor hematitic staining present in blotchy patches.

PETROGRAPHIC NAME: silicified chert-shale breccia

COMMENTS:

Red Dog Creek sample equivalent to Plahuta's silicified PSU unit (Plahuta, 1977).

SAMPLE NUMBER: 208

COLLECTED BY: Kimball Forrest
Mapped as: G

HAND SPECIMEN DESCRIPTION:

Gray-green, tan-weathering chert with a black opaque mineral coating fracture surfaces.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	65	.005 (mm)	Microcrystalline quartz groundmass with jigsaw puzzle quartz infilling pore spaces and chalcedony infilling veinlets.
Carbonate	25	.035 (mm)	Carbonate rhombs both dispersed and coalescing into laminations // to bedding. Darker rhombs with reddish hue could be siderite.

Accessory Minerals	%	Avg. Grain Size	Textures
Mica	9	.004 x .025 (mm)	Occurs as elongate flakes, some of which are // to sedimentary laminae (60%), and some of which are randomly oriented. Could be representative of both authigenic and terrigenous mica.
Hematite	1		Hematitic staining along fractures and scattered throughout the thin section.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 209 COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Homogeneous gray chert.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	85	.003 (mm)	Microcrystalline quartz groundmass with jigsaw puzzle quartz that has totally replaced chalcedony in spherulites. Minor, later-stage, vein quartz infilling after barite.

Accessory Minerals	%	Avg. Grain Size	Textures
Barite	7	.1 (mm)	Infilling veinlets
Mica	4	.003 x .015 (mm)	Widely dispersed randomly oriented elongate crystals.
Unidentified mineral	3	.008 x .045 (mm)	Elongate crystals with low relief, and low birefringence randomly oriented throughout the thin section.
Carbonate	1	.5 (mm)	A few random blocky crystals of calcite.

PETROGRAPHIC NAME: chert

COMMENTS:

SAMPLE NUMBER: 210 COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Carbonaceous chert with chartreuse weathering fracture surfaces.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	80	.03 (mm)	Jigsaw puzzle quartz groundmass. Chalcedony spherulites partially replaced by jigsaw puzzle quartz. Early quartz infilling veinlets.

Accessory Minerals	%	Avg. Grain Size	Textures
Brown organics & clays	10		Unevenly distributed patches of amorphous brown organics and clays.
Gypsum	5	.1 (mm)	Late infilling after quartz veinlets.
Unidentified opaque	3		Unidentified black opaque infilling interstitial space between gypsum grains in veinlets and also as irregularly shaped grains within quartz groundmass.
Pyrite	2	.01 (mm)	Widely dispersed anhedral grains.

PETROGRAPHIC NAME: carbonaceous chert

COMMENTS:

SAMPLE NUMBER: 211 COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Conchoidally fracturing black chert with white-weathering surfaces and rusty-weathering fractures.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	85	.003 & .015 (mm)	Predominantly microcrystalline quartz groundmass with jigsaw puzzle quartz having completely replaced chalcedony spherulites. Some small veinlets infilled with jigsaw puzzle quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	10	.015 (mm)	Micrite as finely disseminated inclusions in quartz. Carbonate rhombs dispersed throughout comprising 40% of total carbonate.
Gypsum	4	.07 (mm)	Infilling veinlets after quartz.
Mica	1	.005 x .03 (mm)	Elongate mica flakes widely dispersed and randomly oriented throughout the thin section.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 212 COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Gray-green chert with a black opaque mineral coating fracture surfaces.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	84	.003 & .02 (mm)	Microcrystalline quartz groundmass forming laminae with interlaminar spaces being infilled with jigsaw puzzle quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	10	.05 (mm)	Micrite as finely disseminated inclusions in quartz. Carbonate rhombs dispersed throughout the groundmass comprising 50% of total carbonate.
Unidentified mineral	4	.01 x .05 (mm)	Elongate crystals having low relief and low birefringence and no observable cleavage (much like quartz) but aligned // to original bedding.
Pyrite	1	.02 (mm)	Widely dispersed euhedral crystals unrelated to any sedimentary features.
Hematite	<1		Hematitic staining occuring in a few localized places associated with an unidentified black opaque occuring as irregularly shaped grains.
Mica	<1	.003 x .015 (mm)	A few randomly oriented elongate flakes.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 215 COLLECTED BY: John Nold

HAND SPECIMEN DESCRIPTION:

Carbonaceous chert with rusty-weathering fracture surfaces.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	65	.003 & .01 (mm)	Microcrystalline quartz and jigsaw puzzle quartz groundmass with jigsaw puzzle quartz completely replacing chalcedony spherulites.
Brown organics	23		Thick, dense mass of organics in thinly laminated beds. Where organics are weathering away, more transparent horizons of quartz can be observed.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	5		Micrite and carbonate rhombs occur within the quartz groundmass.
Unknown mineral	2	.01 x .065 (mm)	Elongate crystals having low relief and low birefringence oriented // to bedding. N is less than balsam, undulatory extinction, possibly orthoclase feldspar.
Gypsum	2	.15 (mm)	Infilling veinlets along with quartz.
Pyrite	1	.008 (mm)	Widely dispersed euhedral crystals.
Hematite	1	.01 (mm)	Common as a stain along fractures associated with unidentified black opaque mineral.
Mica	1	.005 x .02 (mm)	Widely dispersed elongate grains oriented // to bedding. Also some randomly oriented grains.

PETROGRAPHIC NAME: carbonaceous chert

COMMENTS:

SAMPLE NUMBER: 220 **COLLECTED BY:** Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Pyritic, highly carbonaceous chert that is intensely folded

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	62	.003 & .01 (mm)	Microcrystalline quartz groundmass, perhaps originally bedded, but deformation has completely disrupted primary textures.
Brown organics	15		Organics form dense amorphous matter throughout thin section.
Unidentified opaque	12		Abundant irregularly shaped agglomerates of black opaque mineral which is most abundant along fractures, but is also associated with brown organics.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	5	.08 (mm)	Widely dispersed anhedral crystals of pyrite.
Carbonate	3		Some rhombs of carbonate.
Barite	3	.06 (mm)	Barite commonly infills voids and relict spherulites along with jigsaw puzzle quartz.
Hematite	1		Minor hematitic staining along fractures.

PETROGRAPHIC NAME: carbonaceous chert

COMMENTS:

SAMPLE NUMBER: 221 COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Brownish-black siliceous shale; rusty-weathering with disseminated pyrite crystals.

ROCK NAME: carbonaceous siliceous shale

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Brown organics	65		Massive brown amorphous matter comprising the largest percentage of the thin section.
Quartz	26	.02 (mm)	Predominantly jigsaw puzzle quartz. Spherulites are completely infilled with jigsaw puzzle quartz subrounded by brown organics. Also some minor subrounded terrigenous grains 5% of total quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Unidentified opaque	5		Black, irregularly shaped, opaque mineral occuring both associated with organics and as a secondary mineral infilling interstices in veinlets.
Pyrite	3	.015 (mm)	Widely disseminated anhedral to euhedral crystals of pyrite.
Hematite	1		Hematitic stain along fractures.

PETROGRAPHIC NAME: carbonaceous shale

COMMENTS:

Thin section too thick.

SAMPLE NUMBER: 222 | COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Black chert: microbrecciation, rough-weathering surfaces with disseminated grains of pyrite.

ROCK NAME: chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	70	.003, .015 & .075 (mm)	Occurs as microcrystalline quartz groundmass and jigsaw puzzle quartz in both breccia fragments and small crosscutting veinlets. Larger veinlets infilled with granular quartz. Also, chalcedony present infilling some veinlets that have been fragmented and brecciated by later quartz veining.
Carbonate	15	.070 (mm)	Present as carbonate rhombs within breccia fragments.

Accessory Minerals	%	Avg. Grain Size	Textures
Brown organics	10		Forms brown amorphous matter that helps delineate relict breccia fragments.
Pyrite	3	.03 (mm)	Widely dispersed euhedral crystals.
Unidentified opaque	2		Infilling small fractures.

PETROGRAPHIC NAME: chert breccia

COMMENTS:

SAMPLE NUMBER: 225 COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Black chert: translucent, conchoidally fracturing, with numerous quartz veinlets.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	80	.01 (mm)	Predominantly jigsaw puzzle quartz groundmass. One veinlet infilled with feathery textured quartz. (Chalcedony being replaced by jigsaw puzzle quartz). Also some granular quartz infilling pore spaces.
Brown organics	15		Amorphous brown matter following bedding in laterally discontinuous laminae.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	4	.03 (mm)	Widely dispersed carbonate rhombs.
Unidentified opaque	1		Black opaque infilling small fractures.

PETROGRAPHIC NAME: carbonaceous chert

COMMENTS:

SAMPLE NUMBER: 227 COLLECTED BY: Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Medium gray to dark gray chert: pyritic but not highly carbonaceous.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	95	.02 (mm)	Jigsaw puzzle quartz groundmass with some chalcedony spherulites and veinlets infilled with jigsaw puzzle quartz. Quartz groundmass has been fractured and brecciated.

Accessory Minerals	%	Avg. Grain Size	Textures
Unidentified opaque	5		Black opaque mineral infilling fractures and infilling interstices between breccia fragments.

PETROGRAPHIC NAME: chert

COMMENTS:

SAMPLE NUMBER: 228 **COLLECTED BY:** Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Carbonaceous chert: translucent, conchoidally fracturing with rusty-weathering surfaces.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	85	.015 & .1 (mm)	Jigsaw puzzle quartz groundmass with granular quartz infilling veinlets. Some chalcedony spherulites being replaced by jigsaw puzzle quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Brown organics	10		Amorphous brown matter deposited in irregularly bedded laminae.
Unidentified opaque	5		Infilling fractures and occasional pore spaces between quartz grains.

PETROGRAPHIC NAME: carbonaceous chert

COMMENTS:

SAMPLE NUMBER: 230 **COLLECTED BY:** Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Black chert: highly carbonaceous, pyritic and rusty-weathering.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	50	.02 (mm)	Predominantly jigsaw puzzle quartz groundmass and jigsaw puzzle quartz replacing chalcedony in spherulites. Granular quartz infilling veinlets.
Brown organics	40		Amorphous brown matter forming dense sedimentary laminae covering jigsaw puzzle quartz, except for the spherulites, which have been infilled by quartz. Occasionally find spherulites also infilled with brown organics leaving an outer rim of quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Unidentified opaque	7		Infilling interstitial pore spaces in both quartz veinlets and between quartz grains throughout the thin section.
Hematite	2		Hematitic staining around relict pyrite and coating fracture surfaces.
Mica	1	.003 x .025 (mm)	Minor widely disseminated elongate grains aligned // to sedimentary laminations.

PETROGRAPHIC NAME: carbonaceous chert

COMMENTS:

SAMPLE NUMBER: 231 **COLLECTED BY:** Kimball Forrest

HAND SPECIMEN DESCRIPTION:

Black, gray-weathering, chert: Possibly calcareous and highly carbonaceous.

ROCK NAME: carbonaceous chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Brown organics	70		Brown amorphous matter forming very irregular sedimentary lamellae. Irregularly shaped lenses and patches suggest soft sediment deformation.
Quartz	27	.002, .01 & .1 (mm)	Groundmass of microcrystalline quartz. Numerous subrounded terrigenous quartz grains comprise 5% of the total quartz content.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	2	.003 (mm)	Widely dispersed microcrystalline grains.
Mica	1	.002 x .01 (mm)	Elongate crystals widely dispersed and randomly oriented.

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

Thin section too thick.

SAMPLE NUMBER: 401 COLLECTED BY: Al Silverman

HAND SPECIMEN DESCRIPTION:

Highly carbonaceous siliceous shale with numerous silica veinlets and disseminated pyrite.

ROCK NAME: carbonaceous siliceous shale

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	80	.005 (mm)	Microcrystalline quartz groundmass. Numerous subangular terrigenous quartz grains comprise 3% of total quartz content.

Accessory Minerals	%	Avg. Grain Size	Textures
Brown organics	10		Laminated lenses and patches of brown amorphous matter. Laminae are numerous, .015 mm thick, and well developed even though laterally discontinuous.
Pyrite	8	.025 (mm)	Occurs as widely disseminated euhedral crystals that occasionally concentrate along laminae.
Unidentified opaque	1		Black opaque infilling interstices in veinlets between quartz grains.
Mica	1	.005 x .025 (mm)	Numerous elongate flakes aligned // to sedimentary lamellae.

PETROGRAPHIC NAME: carbonaceous siliceous shale

COMMENTS:

SAMPLE NUMBER: 407 COLLECTED BY: John Lufkin

HAND SPECIMEN DESCRIPTION:

Brownish-black chert with conchoidal fracturing: occasional veinlets of quartz and carbonate.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	95	.015 (mm)	Groundmass of jigsaw puzzle quartz. Also note chalcedony spherulites being replaced by quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Carbonate	5	.7 (mm)	Occasional aggregates of blocky carbonate and isolated rhombs of carbonate.

PETROGRAPHIC NAME: chert

COMMENTS:

SAMPLE NUMBER: 410 **COLLECTED BY:** John Lufkin

HAND SPECIMEN DESCRIPTION:

Brown, highly siliceous, shale: numerous crosscutting veinlets of carbonate and quartz; blocky rather than conchoidal fracturing.

ROCK NAME: siliceous shale

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	90	.002 & .02 (mm)	Microcrystalline quartz groundmass. Subangular terrigenous quartz grains comprise 5% of total quartz content. Some granular quartz infilling veinlets.

Accessory Minerals	%	Avg. Grain Size	Textures
Mica	7	.003 x .015 (mm)	Elongate crystals disseminated randomly throughout thin section.
Carbonate	1	.05 (mm)	Some blocky carbonate infilling veins and widely dispersed as carbonate rhombs.
Barite	1	.05 (mm)	Occurs as a late-stage vein infilling after quartz.

PETROGRAPHIC NAME: micaceous siliceous shale

COMMENTS:

SAMPLE NUMBER: 413 COLLECTED BY: John Lufkin

HAND SPECIMEN DESCRIPTION:

Dark gray chert with brecciated texture caused by numerous micro-fractures infilled with black opaque mineral. Texture referred to as "crackle breccia".

ROCK NAME: chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	77	.02 (mm)	Groundmass of jigsaw puzzle quartz. Chalcedony infilling some veinlets. Several generations of quartz are indicated by veinlets of microcrystalline quartz crosscutting jigsaw puzzle quartz.
Carbonate	15	.025 (mm)	Widely disseminated rhombs of carbonate.

Accessory Minerals	%	Avg. Grain Size	Textures
Unidentified	8		Black and brown opaque minerals line numerous fractures with the black opaque infilling the fracture and the brown opaque surrounding the fractures as well as being disseminated into the rock.

PETROGRAPHIC NAME: calcareous chert breccia

COMMENTS:

SAMPLE NUMBER: 414 COLLECTED BY: John Lufkin

HAND SPECIMEN DESCRIPTION:

Dark gray chert breccia with black opaque mineral infilling fracture surfaces. Chert is also calcareous with finely disseminated pyrite crystals widely dispersed throughout the rock.

ROCK NAME: calcareous chert breccia

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	50	.003, .05 & .3 (mm)	Quartz occurs as microcrystalline quartz and jigsaw puzzle quartz with some quartz grains elongate // to their c axis: suggestive of reticulate texture. Also some granular quartz infilling veinlets.
Carbonate	35	.1 (mm)	Blocky crystals of carbonate form one large clast surrounded by quartz. Within this clast, quartz appears to be replacing carbonate. Carbonate rhombs are widely disseminated throughout quartz groundmass.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	10	.07 (mm)	Widely dispersed euhedral crystals of pyrite.
Unidentified opaques	5		Black and brown opaques surrounding fractures. Black opaque infills fracture, while brown opaque surrounds it.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 415 COLLECTED BY: John Lufkin

HAND SPECIMEN DESCRIPTION:

Gray-green chert: Weathers tan; black opaques infilling micro-fractures that could be carbonaceous material or manganese oxides.

ROCK NAME: chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	84	.015 (mm)	Jigsaw puzzle quartz and microcrystalline quartz groundmass. Quartz groundmass is all one generation, but has both jigsaw puzzle and microcrystalline textured quartz.
Carbonate	10	.04 (mm)	Widely disseminated carbonate rhombs and minute carbonate inclusions within quartz.

Accessory Minerals	%	Avg. Grain Size	Textures
Barite	3	.1 x .4 (mm)	Randomly oriented laths of barite being replaced by jigsaw puzzle quartz.
Hematite	1		Occurs as a stain on some grains, usually carbonate rhombs. Could be siderite.
Unidentified opaques	1		Black opaque mineral infilling small fractures.
Mica	1	.003 x .015 (mm)	Widely disseminated elongate crystals randomly oriented throughout the thin section.

PETROGRAPHIC NAME: calcareous chert

COMMENTS:

SAMPLE NUMBER: 502 **COLLECTED BY:** Bill Matlack

HAND SPECIMEN DESCRIPTION:

Dark gray to tan, rusty weathering chert with numerous silica veinlets

ROCK NAME: Chert

PETROGRAPHIC DESCRIPTION:

Primary Minerals	%	Avg. Grain Size	Textures
Quartz	97	.70 .20 & .02 (mm)	Microcrystalline quartz groundmass with jigsaw puzzle quartz replacing chalcedony spherulites. Also some elongate quartz grains present which are suggestive of reticulate texture. Granular quartz infilling veinlets.

Accessory Minerals	%	Avg. Grain Size	Textures
Pyrite	2	.10 (mm)	Abundant widely disseminated anhedral and euhedral grains.
Hematite	< 1		Hematitic staining along veinlets and around some spherulites.
Carbonate	< 1	1.0 (mm)	One or two isolate rhombs of carbonate.

PETROGRAPHIC NAME: Chert

COMMENTS:

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

David J. Norman
Adviser

[illegible]

Frederick J. Sawkins

[illegible]

10 December 1980
Date