

ORIGIN OF THE QUARTZ DEPOSIT AT FAZENDA PACÚ, BRAZIL

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ABSTRACT

The quartz of Fazenda Pacú occurs in veins which are formed along a fracture zone at the contact between granite (Archean) and argillaceous sediment (Silurian). Rock decay has decomposed the granite and altered the binding material of the quartz of the veins. Kaolinite has resulted. Erosion has removed the upper part of some veins, redepositing the crystals in boulder beds separated by sedimentary clay. The crystal-bearing veins are probably of hypogene origin and are related to a later phase of the prominent pegmatitic invasions which have occurred in Minas Geraes.

INTRODUCTION

Rock crystal has been mined in Brazil for many years. Early production was for ornaments or optical purposes, much of the crystal being shipped to the Orient for cutting or carving. Bauer (1904) states that 200 persons in the space of two years collected 7000 tons of material in the Serra dos Cristaes along the border of the states of Minas Geraes and Goyaz. More recently the use of quartz in radio and telephone equipment has resulted in renewed activity at many of the long known crystal producing localities. Quartz suitable for commercial use is being found in the states of Minas Geraes, Baía, Goyaz, Matto Grosso, and Amazonas, production from the first named being the most important. Various localities have been referred to in the literature in brief accounts by Leonardos and Moraes (1936), Oliveira (1938), Freyberg (1934), Walls (1929), Andrade (1941), and Wright (1941). The most productive deposit from the standpoint of large clear crystals is Fazenda Pacú, where five hundred men are employed in the diggings.

Fazenda Pacú (large ranch) lies about four hundred and fifty miles north of Rio de Janeiro in the central part of the state of Minas Geraes (Fig. 1). It is twenty-five miles from Sete Lagôas, the nearest railroad station, and eighty-five miles northwest of Belo Horizonte, the capital and principal city of the state.

Quartz has been known to occur here for a long time, but it has been only in the last few years that exploitation on a considerable scale has been attempted. The pits occur in five localities over a stretch of about seven miles, extending along a northwest-southeast line with the ranch house of Fazenda Pacú a mile and one-half from the southern end. The names of the mine workings (Fig. 2) listed in order from north to south are Pontinha, Manga Grande, Pastinho, Açudinho, and Onca. Pontinha

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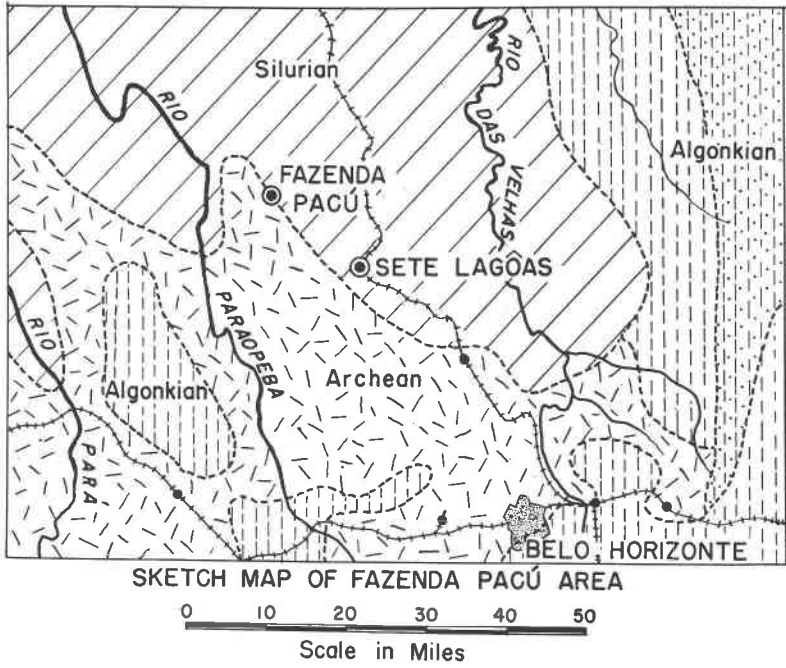


FIG. 1. The location of the quartz deposit.



FIG. 2. Diagram showing the relative positions of the quartz bearing localities of Fazenda Pacú.

lies about five miles northwest of Manga Grande, which in turn is about one thousand feet south and west of the ranch house. Pastinho is a little more than one-half mile east of Manga Grande. Acudinho adjoins Pastinho on the southeast.

The workings at Onca are distributed along a zone 1300 feet long and 150 feet wide, while the areas mined in the other localities appear to be in each case from one half to three quarters as extensive. The maximum depth mined is about fifty feet. All of the work is carried on by hand and mule carts haul the spoil to nearby dumps. Dirt is hoisted from the bottom of the pits by shovel relay, as many as seven benches forming the side of some pits where workmen stand, each in turn shoveling dirt onto the bench above and thence into a mule cart. When water is encountered excavation stops, unless the water can be easily drained.

Quartz crystals occur in a soft matrix of decomposed material and are pried loose with picks. An abundance of quartz occurs in the material being mined, but only a small part of it is worth saving. This is piled and carried to the warehouse where it is sorted and trimmed for shipment by truck to Sete Lagôas and Belo Horizonte where further selection occurs.

Of the material mined not more than one crystal in a hundred is saved. Many of the crystals are cloudy or fractured, or occur in intergrown groups too small or too irregular to be satisfactory for electrical or optical use.

To be suitable for piezoelectric use as radio oscillators or for control in long distance telephony, the crystals must be sound individuals, uniform and clear. Twinning, inclusions, fractures, and intergrowth interfere with the utility of the material. In order to detect imperfections, all crystals are examined by a strong light; also in an illuminated box filled with immersion media and containing windows on opposite sides covered with crossed polaroid sheets.

ACKNOWLEDGMENTS

The writers wish to acknowledge the kindness of Mr. Redelvim Andrade and Dr. Newton Andrade for the courtesy of visiting Fazenda Pacú and their help in furnishing significant specimens. It is also a pleasure to acknowledge the assistance of the Carnegie Endowment for International Peace which has made this joint study possible. The kind cooperation of Dr. Luciano Jacques de Moraes, Director of the Departamento Nacional da Produção Mineral, Dr. Glycon de Paiva, Director of the Divisao de Fomento da Produção Mineral, and Dr. Anibal Alves Bastos, Director of the Divisao de Geologia e Mineralogia, in making available the facili-

ties of the government services, is greatly appreciated. We wish further to express our appreciation of the opportunity for discussion of the problem of the origin of the quartz with Dr. Arrojado Lisboa, chief of the Belo Horizonte section of the Fomento da Produção Mineral, and with his associate, Dr. Emilio Teixeira. We also wish to acknowledge the assistance of Dr. Djalma Guimarães, formerly with the department, who has written numerous contributions on Brazilian geology.

GENERAL GEOLOGY

Although a general account of quartz production at this locality has been published by Andrade (1941), little study has been made of the geological occurrence. In view of the present importance of this source of crystal quartz, it would seem worth while to record a number of geological observations in a preliminary description. It is regretted that our visit was too short to allow us to complete a study of the field relations and map the pits in detail.

The geologic map of the State of Minas Geraes by Djalma Guimarães and Octavio Barbosa (1934) indicates that Fazenda Pacú is located near the contact between the underlying Archean and the unconformably overlying Bambuí series of supposed Silurian age. Along the road between Sete Lagoas and Fazenda Pacú one passes prominent exposures of Bambuí sediments, chiefly limestone, but containing intercalated argillaceous strata.

The evidence of infrequent exposures appears to confirm the accuracy of the geologic map. It is possible that a small amount of the Algonkian phyllite, which occurs between the Archean and Silurian in places and has not been mapped in its entirety, might be present, although this is not considered likely, since the lithology is more typical of the Silurian.

Just west of Onca, the southern pit of the Fazenda Pacú group, is a good exposure of fresh granitic rock with float of biotite gneiss nearby. Building blocks have been cut for construction purposes from the granite. The fresh exposure forms part of a group of outcrops to be found in the vicinity and constitutes the nearest exposure observed containing unweathered granitic rock. The distance of the granite from the Onca pit is about 1300 feet. The formation is presumably Archean.

In evaluating the geological evidence concerning the origin of quartz at Fazenda Pacú, it should be kept in mind that the region is one in which the process of weathering has penetrated to an unusual depth. The matrix of the quartz crystals has been completely decomposed and it is now possible to pry them loose from a bonding of clay in all parts of the various deposits. The lower limit of rock decay has not yet been disclosed. Alteration appears just as intense fifty feet below as at the surface, and

it is claimed by local geologists that borings indicate weathering in some parts of Minas Geraes may extend three hundred feet or more below the surface.

The weathering effects have been irregular in their development, some rocks being little affected, others being completely decomposed. Subsequent erosion has removed the decomposed material irregularly, sweeping bedrock bare in some places and leaving scores of feet of rock decay in others. The quartz crystals are distributed through clay-filled fracture zones bordered by argillaceous strata or kaolinized granitic rock. Under such circumstances the nature of clays associated with the quartz at Fazenda Pacú is of considerable interest.

The general geology of Minas Geraes has been discussed by various authors. Harder and Chamberlin (1915) have furnished an excellent account of the geological features in the central part of the state, but unfortunately their observations did not include the area in the vicinity of Sete Lagôas. Branner (1919) in his outline of the geology of Brazil, written to accompany the geological map of the country, gives references to the work on Brazilian geology up to the time of his publication. Miller and Singewald (1919) have provided a most useful bibliography. Gerth (1932) has furnished a general discussion and a sketch map of the geological features of Minas Geraes. The geology of Brazil by de Oliveira (1940) with a general geological map furnishes a substantial revision of the earlier study by Branner. The most satisfactory geological map for general use in Minas Geraes is the state map by Guimarães and Barbosa (1934) referred to above.

NATURE OF THE DEPOSITS

A generalized section through the quartz pit at Onca is shown in Fig. 3. On the right, or east, is white and pink decomposed material believed to be kaolinized granite. The megascopic and microscopic texture compares favorably with the texture of the granite partly weathered in situ observed about 1300 feet west of Onca pit. It consists of specks of limonite in positions probably at one time occupied by the ferromagnesian minerals. Grains of anhedral quartz lie in approximately their original position and white kaolin occupies the positions of the original feldspars. The exposures of kaolinized granite in the quarry cuts exhibit a fracture pattern now a network of white kaolinite veins crisscrossing pink weathered granite. Cuts have not penetrated deep enough to encounter fresh granite in the workings.

Separating the decomposed granite from the quartz zone in the pits at Onca is a white kaolinized belt several feet thick which forms the foot-wall or east side of the vein system. The hanging wall or west side of the

vein system is made up of a well stratified argillaceous sediment. Exposures of a red shale were identified by Dr. Arrojadó Lisboa as having the megascopic characteristics of the Silurian.

The sedimentary series is cut by vein quartz and in places veins have penetrated along bedding planes (Fig. 4). This feature is shown in several places at Onca where it is possible to observe parallel horizontal veins an inch or two in thickness and several inches to a foot apart. The veins are solid but grade into veins which yield crystals. The horizontal veins also curve gradually along the strike, eventually cutting across beds and joining those which are thick and steeply inclined.

The sedimentary series has been cut by tongue-like veins of quartz and in places has been distorted and displaced. Deformation of the Silurian strata is well shown near the larger quartz zone on the east side of the pit where the beds are steeply inclined, bent and broken in contrast to the moderately inclined and virtually unbroken strata on the edge of the vein-bearing area to the west. Solutions depositing quartz evidently followed the fracture pattern produced by the deformation, forming a stock-work of veins.

The clay matrix of the quartz is now largely kaolin. Veins contain decomposed fragments of argillaceous wall rock. Manganese and iron are present in minor amount. Sericite, so common in quartz veins, may have been a prominent original constituent, but if so it has not resisted the kaolinization.

Overlying the section just described is a mantle of soil containing fragments of quartz and occasionally loose crystals, the whole forming surface gravel.

Gouge and folding along the side of the main quartz mass (Fig. 5) indicate movement which is also shown by the tilting and, in places, breaking of sedimentary strata. It seems unlikely that the movement was one of great magnitude or the sediments would have been more completely broken. Also, the overlying Silurian strata to the east are more or less horizontal.

The quartz bearing zone appears to strike in general north-south and dips steeply to the west at 60 degrees or more. The trend appears to be the same in each of the pits where material in situ is to be found. Also in each pit a large vein appears to be bordered by a group of smaller veins on the hanging wall side. At times small veins penetrate the decomposed granite of the footwall. On the whole, however, except along the margin of the main crystal zone, where fracturing and vein filling have been greatest, the granite is free from crystals or vein quartz. It seems likely that careful geologic mapping might disclose a vein pattern, since the

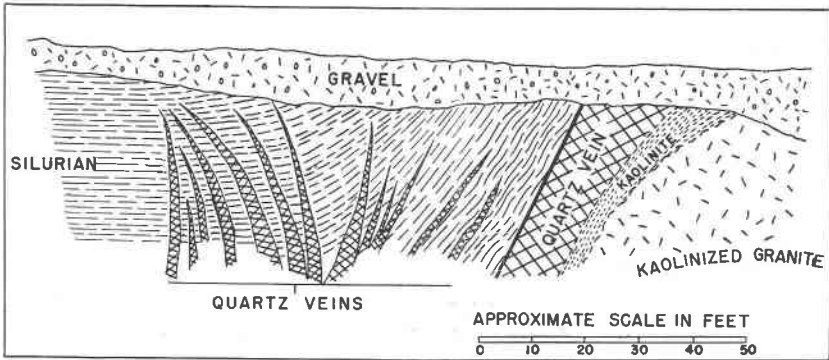


FIG. 3. A generalized section through the quartz pit at Onca, Fazenda Pacú.

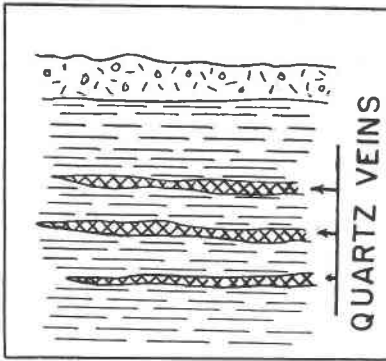


FIG. 4. Quartz veins formed by penetrating the shale series along bedding planes.

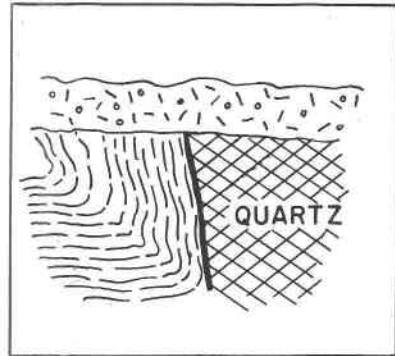


FIG. 5. An exposure about 20 feet across on the quarry wall at Onca showing the deformation of the shale series bordering a quartz vein.

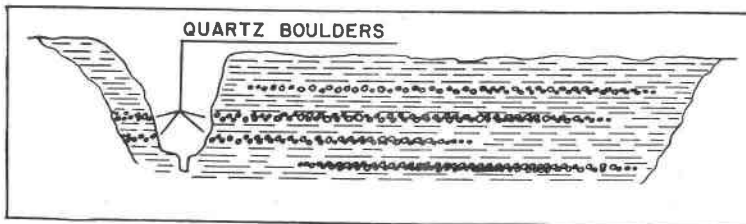


FIG. 6. A quarry face at Açudinho about 100 feet long where quartz crystals occur as rounded boulders forming layers separated by several feet of clay.

relations in the pits where the vein is visible are so similar. Such a study should also be useful in prospecting for intermediate deposits which may be needed to carry on production when mining in pits now being worked reaches an economic lower limit. Several vein systems may exist, but the alignment of operations at present indicates a single set of veins. The pattern of the system should give the key for prospecting the intermediate area between pits.

In addition to the pits where decomposed veins are being mined in situ, a thick deposit of clay and quartz gravel has accumulated at Acudinho. Here quartz occurs in crystals with rounded water worn edges, rounded boulders and small pebbles. These form layers from a few inches to two feet in thickness and are separated by layers of sedimentary clay several feet thick (Fig. 6). Both the clay and crystal boulder layers are horizontal and are exposed for a section 150 feet in length and 35 feet in depth. Nine boulder layers are reported to occur, each separated from the one above and below by several feet of stratified clay. These layers provide some of the best crystals to be found, since the process of water wearing has eliminated the fractured crystals and has reduced the number of imperfections.

CHARACTER OF THE QUARTZ

The quartz zones contain clear crystals, cloudy or milky quartz, clusters of crystals, interlocking crystalline masses, clay material, black manganese oxide stain, limonite, and occasional streaks of goethite. They consist for the most part of heterogeneous masses of quartz in clay.

Crystals are singly terminated with few exceptions and vary from a diameter of a fraction of an inch to prisms a foot thick and three feet long. Nearly all crystals are several times as long as thick, although Dr. Andrade presented the writers with a doubly terminated crystal several inches thick having well developed rhombohedral faces and thin almost negligible prism faces. Such a crystal is rare for the deposit. A clear crystal weighing 330 pounds has been described by Andrade (1941) as having been found at this locality.

Large quartz crystals have been found in a number of localities in Brazil. A mass of clear optical quartz weighing approximately one thousand pounds was exported from Minas Geraes in 1940. Numerous cloudy crystals up to three feet in length and a foot in diameter have been found at Fazenda Pacú.

The largest crystal observed by the writers is the great smoky quartz crystal in the Feira Permanente de Amostras at Belo Horizonte (Figure 10). It deserves a place among the largest quartz crystals ever found. This crystal was discovered at Ariranha in the district at Pavao, the muni-

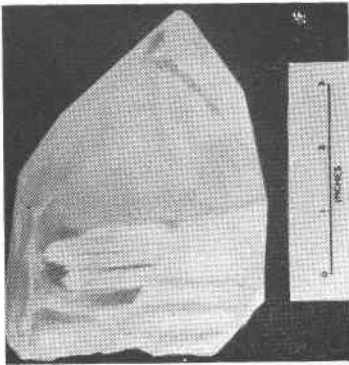


Figure 7

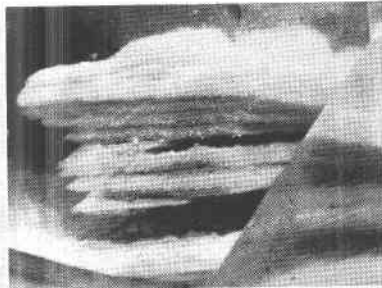


Figure 8

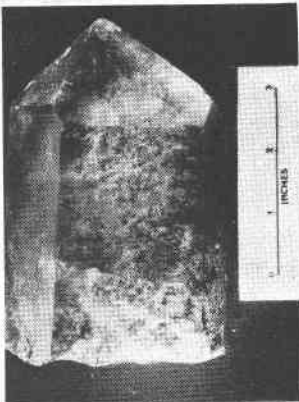


Figure 9



Figure 10

FIG. 7. Quartz crystal from the Diamantina district, Brazil, containing thin plates of altered itacolumite.

FIG. 8. An enlarged view of a portion of Figure 7.

FIG. 9. A quartz crystal from Minas Geraes, Brazil, containing kaolinite believed to have crystallized along with the quartz.

FIG. 10. An unusual quartz crystal from Teófilo Otoni, weighing about five tons, thought to be pegmatitic in origin.

cipality of Teofilo Otoni in Minas Geraes, Brazil. It is 7 feet, 2 inches in height, 11 feet, 2 inches in circumference and weighs more than five tons.

Crystals were observed showing inclusions of kaolinite and itacolumite reported to have been found in the Diamantina district. Rutile or chlorite inclusions, if present, are uncommon. Turbidity, fracture and twinning appear to be the most common defects. Thin sections of turbid crystals show an abundance of fluid inclusions, a sufficient number in fact to account for the turbidity.

ORIGIN OF THE CRYSTALS

Because of the prevalent rock decay, the origin of quartz in Brazil is frequently uncertain. Dr. Luciano J. Moraes (1934) who has examined many crystal localities including the Serra do Cabral, Serra Mineira, and Serra Itacambira, has considered the crystals to occur chiefly in pegmatites, the origin being inferred from the presence of a large quantity of kaolinized material thought to have resulted from the decomposition of pegmatite. At Fazenda Pacú, however, coarse feldspar crystals, tourmaline, garnet, mica, and beryl, the common constituents of Brazilian pegmatites, are conspicuous by their absence. In addition, the structure of the mass indicates little likelihood of these minerals having been once present and later decomposed by weathering.

Dr. Djalma Guimarães who has studied the quartz of the Serra Mineira district in connection with investigations of the origin of the diamond, inclines to the opinion the quartz of the Diamantina district should be considered as vein quartz.* Examination of Silurian areas, he reports, reveals sulphide-bearing quartz veins in the limestone in the proximity of crystal localities. He also suggests that the quartz which has invaded the Silurian, being younger, shows less strain and twinning than is usually found in older pre-Silurian occurrences.

With quartz occurring over such a wide area in Brazil it is only natural to expect to find rock crystal with several types of occurrence. With this in mind, the present discussion centers around the locality of Fazenda Pacú.

The weight of evidence concerning the pressure-temperature conditions of formation of the quartz at Fazenda Pacú points toward moderate temperature vein-forming conditions. The prevalence of fluid inclusions indicates the precipitation of quartz from aqueous solutions, a criterion thus interpreted since the classic work of Sorby (1858). These appear to be both primary and secondary, according to the interpretations of fluid inclusions advanced in the studies of Newhouse (1932). The abundance

* Personal communication.

of large crystals having a minimum of twinning with a simple prismatic form favors the conclusion that the original solutions yielded alpha-quartz (Wright and Larsen, 1909). Open cavities in the veins and lack of compaction of the wall rock suggests a moderate load of overlying sediment and low pressures.

A quartz crystal from an unknown locality in the region (Fig. 9) contains abundant inclusions of kaolinite. The inclusions form accordion-like clusters, each several millimeters in length. Some clusters are completely surrounded by the silica. They are concentrated at the base of the crystal where it was attached to the enclosing wall and extend along one side. A large part of the crystal, however, is clear quartz, but intricately twinned as shown in thin section. Since the hydration curve of kaolinite breaks sharply at 450° C., it seems likely that the temperature of formation of the crystal was lower, or the kaolinite would not have retained its form as shown in thin section.

In the last hundred years a considerable number of experiments have been made in which alpha-quartz has been crystallized from solution. Crystallization of quartz has been claimed in some experiments as low as 180° C., and the mineral has apparently been formed by a number of investigators at temperatures between 200° C. and the inversion temperature. The literature on this subject has been reviewed by Morey and Ingerson (1937). A survey of these experiments would indicate the likelihood that quartz might easily form in nature from thermal solutions within the temperature range indicated.

Freyberg (1934) has discussed the occurrence of quartz in the Serra do Cabral, a mountain range some distance northwest of Diamantina in the province of Minas Geraes. From his description it would appear that crystals occur in areas of white quartzite belonging to the Itacolumite series. The deposits of clear crystal quartz tend to form along the crests of anticlines, and apparently the clear quartz crystals have been crystallized from solutions which have derived silica from the quartzite.

Walls (1929) has discussed the origin of crystal in the vicinity of Diamantina. He believes that crystals have been formed by solution as a secondary product derived from quartz present in great beds of quartzite. The solutions he considers thermal in character, carrying such constituents as would result in the formation of extremely fine potash mica and at the same time would also produce large clear quartz crystals.

Accompanying photographs of a quartz crystal may typify this occurrence. The crystal unfortunately was not found in place, but was considered by those familiar with the Diamantina district to have come from that locality. Two views of the crystal are shown in Figs. 7 and 8. The

second view (Fig. 8) is a close-up of a portion of the first. Aside from the inclusions there is nothing unusual about the crystal. The inclusions, however, represent a group of more or less separated layers believed to be undigested portions of thin bedded quartzite from the Itacolumite formation in which crystals are known to occur. The stratification is suggestive and is well exhibited, particularly on the base of the crystal where a cut was made to obtain a chip for a thin section. The thin section shows the presence of sericite in the layers.

It would appear from Walls' description of quartz in the Diamantina district that large crystals of clear quartz form along fracture zones which have been filled with fine sericite mica, the quartz crystals being oriented with their *c*-axes normal to the walls of the fractures. The evidence from the crystal described above would appear to support his conclusion that the crystals were precipitated from silica-bearing solutions, the silica being derived in a large degree from the enclosing wall rock.

CONCLUSIONS

While rock crystal of pegmatitic origin may be common in Brazil, it seems reasonable to conclude that the crystal at Fazenda Pacú has resulted from vein forming solutions. These have forced their way upward along fractures. Crystals have formed in the gouge and in openings in the broken strata at or near the boundary between the Bambuí sediments and the Archean granite. Actual vein forming conditions have probably been similar to those existing in other parts of the world where large accumulations of vein quartz have formed from solution. Brazil has been so much more productive of crystal quartz not merely because of large and widespread accumulations, but chiefly because of the weathering which has reduced the associated matrix to a clay. Under such conditions it is possible to select by inexpensive hand labor the one crystal in each hundred or more worth saving. The widespread distribution and the occasional formation of large, clear crystals are features which should not be minimized, but by themselves could hardly be considered limited to Brazil.

The temperature of formation was probably moderate, the quartz belonging to the alpha-phase. It may have formed at temperatures considerably below the inversion point. Pressure was probably a minor factor. Although not considered pegmatitic, the solutions might have yielded pegmatites at depth. In any event, it seems difficult to conceive of solutions being other than hypogene in a region of such widespread metamorphism.

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