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THE CAUSE OF COLOR IN ROSE QUARTZ

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I. INTRODUCTION

The growth of the literature on the subject of allochromatic coloring in minerals is but another indication of the trend of mineralogical research away from a mere recording of physical and chemical properties to the more fundamental and more fascinating study of the causes for the observed phenomena. A survey of that literature, however, shows that the work done on the subject has been largely of a general nature. Investigators have studied one or two specimens each of many minerals, rather than a large number of specimens of one mineral. The result is that for most allochromatic species the question of what causes their color is an open one, whose solution is only inferred.

The work described in this paper represents an intensive study of only one mineral, rose quartz. The nature of its pigment was investigated by all the methods which have been employed in such researches; by analysis, by the observation of its absorption spectrum and its pleochroism, by attempts to reproduce the color synthetically, through the study of its decolorization by heat and its behavior when exposed to radiation by radium preparations. The work on decolorization and the effect of radiations was carried out by Drs. S. C. Lind and D. C. Bardwell[1] of the U. S. Bureau of Mines, at the Reno, Nevada, station. The writer wishes to express his great indebtedness for this assistance.

In this investigation 21 specimens of rose quartz, from as many localities, were used. Several specimens of ordinary white pegmatitic quartz were also studied for comparison with the rose quartz. The following table lists these specimens, with their locality, the source from which they were obtained, and the number by which they are designated in this paper. They are arranged in 13 classes on the basis of the depth of their color;

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[1] Dr. Bardwell continued the work after Dr. Lind's transfer to Washington, in June. The work was begun in January and concluded in October, 1923

passing from class i, deep rose, to class xiii, white. This classification was made by Dr. Lind. The writer wishes to acknowledge the assistance of the following, in securing the specimens: Prof. T. L. Watson, University of Virginia; Prof. C. Palache, Harvard University; Messrs. J. W. Eggleston, Riverside, Cal.; M. Vonsen, Petaluma, Cal.; A. O. Woodford, Claremont, Cal.; Lazard Cahn; G. S. Scott; and Ward's Natural Science Establishment.

TABLE I. LOCALITY AND SOURCE OF THE SPECIMENS USED IN THE EXPERIMENTS AND ANALYSES

(ARRANGED IN 13 CLASSES ACCORDING TO DEPTH OF COLOR)

SPEC. NO.	COLOR	COLOR CLASS	LOCALITY	SOURCE
30	Very deep rose–67″d[3]	i	Rossing, S. W. Africa	C. Palache
12a[2]	Deep rose 67″e	ii	Sahanisota, Madagascar	Ward's Nat. Sci. Est.
1		iii	Bad Lands, S. D.	Univ. of Mich. collection
9		iii	Pisch, Bohemia	Ward's Nat. Sci. Est.
8		iv	Rubenstein, Germany	Ward's Nat. Sci. Est.
20	Rose 67″f	v	Minas Geraes, Brazil	Ward's Nat. Sci. Est.
21a[2]		v	Tulare Co., Cal.	M. Vonsen
16		vi	Custer, S. D.	Univ. of Mich. collection
7		vi	Twiesel, Bavaria	Univ. of Mich. collection
28		vi	Cahuilla, Riverside Co., Cal.	M. Vonsen
14	Pale rose 67″g	vii	Oxford Co., Me.	Lazard Cahn
11		viii	Grafton, N. H.	Ward's Nat. Sci. Est.
18		ix	Dodgington, Ct.	G. S. Scott
10		ix	Acworth, N. H.	Ward's Nat. Sci. Est.
17		ix	I. of Shikoku, Japan	G. S. Scott
13		ix	Southbury, Ct.	Lazard Cahn
19		x	Newton, Ct.	G. S. Scott
24		x	West Riverside, Cal.	J. W. Eggleston
2		xi	Bedford, N. Y.	Univ. of Mich. collection
23	Very pale rose–67″g	xii	Pala (?), Cal.	J. W. Eggleston
3		xii	Paris, Me.	E. F. H.
12b[2]	White	xiii	Sahanisota, Madagascar	Ward's Nat. Sci. Est.
4		xiii	Deering, N. H.	E. F. H.
21b[2]		xiii	Tulare Co., Cal.	M. Vonsen
6[4]		xiii	Acworth, N. H.	E. F. H.
27		xiii	Grafton, N. H.	Univ. of Mich. collection
26		xiii	Acworth, N. H.	E. F. H.

[2] 12a and 12b, and 21a and 21b, respectively, are differently colored parts of the same specimen.

[3] The colors in terms of Ridgway's scale (Robert Ridgway, Color Standards and Color Nomenclature, Washington, 1912).

[4] This is a very granular sugary quartz, apparently white; but very pale rose in transmitted light

II. THE PHYSICAL PROPERTIES OF ROSE QUARTZ

Rose quartz varies in color from a faintly perceptible pink through all intermediate tints to a deep rose; corresponding to Ridgway's 67″d, laelia pink. The mineral has a vitreous to greasy lustre, and is either transparent with a clear jelly like appearance, or translucent, never entirely opaque. Rose quartz is practically always opalescent and exhibits asterism. Kalkowsky[5] fully discusses this, but states that the color has nothing to do with the asterism.

The amount of impurities present in rose quartz is so small as to have no appreciable effect on its density or optical constants.[6] Variations in these properties can not be made use of in the determination of the cause of the rose color.

True rose quartz is always *massive*. As noted by the writer,[7] pink *crystals* are sometimes found, but their color may be ascribed to microscopic inclusions of hematite. This differentiates them from rose quartz. The massive form of rose quartz is in sharp contrast to the well crystallized character of amethyst and smoky quartz, and may have some, at present unknown, relation to the differences in the color of these varieties from that of rose quartz.[8]

III. THE OCCURRENCE OF ROSE QUARTZ

It is necessary, for a full treatment of the possible causes of the rose color of this type of quartz, to describe the conditions under which it was formed. Rose quartz occurs almost invariably in association with granitic rocks.[9] It is itself, like white vein quartz, the extremely siliceous differentiation product of an already highly siliceous magma. While this mineral is usually associated with granites, it is actually found in related pegmatites, or in hydrothermal quartz veins, traversing either the country rock or the granite itself.

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[5] Ernst Kalkowsky. *Z. Kryst. Mineral.*, **55**, 23-50, (1915).

[6] Kadokura (*Beitr. Min. Japan*, (1915) **5**, 269-74) gives the indices of rose quartz from Godo as ω_D 1.543950, ϵ_D 1.553215. These agree very closely with the values given for rock crystal: 1.54418 and 1.55328 (Dana).

[7] Edw. F. Holden. *Amer. Mineral.*, **8**, 117-21 (1923).

[8] Lacroix (Mineralogie de Madagascar, **I**, 200; Paris, 1922) says: "It is interesting to note that amethyst is frequent in the drusy crystals of quartz in pegmatites, but never exists in that quartz which goes to make up the rock; on the contrary, the rose quartz, common in the essential quartz of the pegmatites, has never been found in the transparent drusy crystals." Kalkowsky (*op. cit.*) states "free crystals of rose quartz do not exist, the so-designated crystals from Vurcha, India, and Hungary, are not opalescent rose quartz, but are colored in another way."

[9] The writer has found but one instance in the literature in which the parent igneous rock is not a granite. At the Summer Rose claim, Tulare Co., Cal., it is a quartz diorite, but this rock is closely related to granite in its acidic composition. (*U. S. Mineral Resources*, Gems and Precious Stones, 1911, 30-1.)

The aqueous solutions carrying silica also contained mineralizers, such as F, B, and CO_2, which may have aided in the production of the color in the quartz deposited from the solution.

With respect to the associated minerals, deposits of rose quartz may be classified as follows: (a) rose quartz in pegmatites, associated with the ordinary pegmatite minerals (feldspar, mica, black tourmaline, garnet, beryl). Represented by the localities in South Dakota; Colorado; New York; Connecticut; Norway, Maine; in the Waldegebirge; and Montagny and Chanteloube, France. (b) In pegmatites carrying gem-beryl. Madagascar; Albany, Me.; Acworth, N. H.; Rossing, S. W. Africa. (c) In lithium pegmatites. Auburn, Norway, and Hebron, Me. (d) In quartz veins, often with white quartz. New Hampshire; Connecticut; California; Madagascar. (e) With manganese-bearing quartz veins. India; Rabenstein, Bavaria. This is suggestive in connection with the theory that the color of rose quartz is due to a manganese compound. (f) An unusual association, especially since it represents a very peculiar type of rose quartz, is that in the Rochester district, Humboldt Co., Nevada. Here the color is due to numerous fine inclusions of pink dumortierite. "Between the rose quartz and pure pink dumortierite all stages of gradation occur, due to intergrowth. . . ."[10] (g) So-called rose quartz from Långbanshytta in Wermland, Sweden, owes its color to minute particles of manganese silicate.[11]

Wright and Larsen[12] tested four specimens of rose quartz for the temperature at which they were formed, and found that it was in each case below 575°, the inversion point of quartz. These specimens were from Maine (two), Connecticut, and New York. In the case of white quartz associated with pegmatites, 13 out of 16 specimens tested were formed at temperatures higher than 575°. Lacroix[13] observes that the rose quartz of Madagascar was formed below 575°, while the gray pegmatite quartz was usually formed above that temperature. The rose quartz generally occupies the axis of the veins, and represents the last filling. This is of interest in connection with the temperature at which rose quartz is decolorized by heat (see part VIII). Apparently a tem-

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[10] Adolph Knopf. *U. S. Mineral Resources*, ii, 893, (**1916**).

[11] E. Kalkowsky. *Z. Kryst. Mineral.*, **55**, 23-50, (1915).

[12] F. E. Wright and E. S. Larsen. *Amer. J. Sci.*, **26**, 421, (1909).

[13] A. Lacroix. Mineralogie de Madagascar, **11**, 260. Paris, (1922).

perature above the inversion point of quartz prevents the rose coloration.

IV. RADIATIONS AND THE COLOR OF ROSE QUARTZ

The theories to account for the color of rose quartz are: (1) That the color is due to the action of radioactive minerals or solutions upon white quartz. (2) That the color is due to some inorganic impurity. (3) That the color is due to some organic impurity. The last two theories are discussed in part V. Only the first will be considered here.

Doelter's work concerning radium and mineral colors is well known. Among other minerals he has investigated rose quartz. Several books and papers give the details of his work and that of others.[14] It will be sufficient here to state only the theory which Doelter proposes to account for the color of rose quartz, summarize his results, and describe the experiments performed by Dr. Lind in that connection.

It is Doelter's view that rose quartz, and other colored varieties of quartz, may have been derived from colorless or white quartz by the action of radiations from radioactive minerals or solutions. The radiations are assumed to set free colloidal particles of a metal, which produce the color, in the same way that gold particles color colloidal gold solutions. Quartz contains sodium and lithium silicates as impurities, and Doelter suggests that it may be colloidal Na or Li which give rise to the color.

The loss of color on heating is ascribed to changes in the degree of dispersion of the colloidal particles. But Wild and Liesegang[15] point out that is is extremely doubtful that a migration of dispersed particles could take place in the solid framework of crystalline substances.

The results of Doelter's experiments are as follows: Rose quartz when exposed to the radiations from radium preparations gradually changed in color to dark brown or nearly black. This occurred regardless of the gas in which the mineral was immersed (air, O, or N). A low heat discharges this induced color, leaving

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[14] C. Doelter. Das Radium und die Farben, Dresden, (1910); Die Farben der Mineralien, Braunschweig, (1915); *Sitz. k. Akad. Wiss. Wien*, Math.-naturw. Kl. **117,** Abt. 1, 819-44, 1275-1325, (1908); *ibid.* (with H. Sirk) **119,** 1091-1100, (1910); *ibid.* **121,** 891-6, (1912); *ibid.* **129,** Abt. 1, 399-403, (1920); *Centr. Mineral.* (**1909**), 232-4; *Chem. Zentr.*, (**1914**), I, 288. Handbuch der Mineralchemie, **II,** 143.

[15] G O Wild and R. E. Liesegang. *Centr. Mineral.*, 481, (**1922**).

the original rose color. Roentgen rays cause a weak yellow brown color to develop. Ultraviolet light has a tendency to decrease the rose color somewhat.

According to some writers long exposure to sun light diminishes the color of rose quartz. This has probably been exaggerated. Kunz[16] describes ledges of the mineral, in the Black Hills, S. D., which have retained their original color, although presumably exposed to the action of the sun since the retreat of the last continental glacier. The writer has noted similar occurrences in New Hampshire. Lacroix[17] reports prospectors' statements to the effect that in Madagascar the color of rose quartz veins is often deeper at the surface than within the vein.

Dr. Lind, and later Dr. Bardwell, very kindly tested two samples of each of 20 of the writer's rose quartz specimens, and four of the white ones, for their behavior to penetrating radiations from radium preparations. One of the samples of each of the specimens was that of the original rose or white color, while the other had been heat-decolorized. The results are given in Table II, below. In addition Dr. Bardwell exposed manganese-colored silica gels to radium radiations, as described in part IX.

The effect of radium radiations on rose quartz is to invariably produce a color like that of smoky quartz. The heat-decolorized and naturally white specimens (color class xiii) behave in the same manner as those which are rose colored. In 20 of the 24 specimens one week's radiation with 230 mg. radium produced a moderately to very dark smoky color. Of the other four samples (nos. 24, 2, 23 and 6) a second week's further radiation brought three to a dark color. Only no. 6 was resistant to coloring. This was a granular, sugary, nearly opaque specimen, apparently white, but pale rose in transmitted light. It suffered but slight change in color, due probably to its granular structure. This should act to greatly reduce the color, the effect being analogous to the white color of the powder of allochromatic minerals.

Undoubtedly the smoky coloration is one superimposed upon the rose color, and in no way related to it. It has never been possible to reproduce by the action of radium the color of rose quartz, either upon naturally white or colorless quartz, or upon heat-decolorized rose quartz.

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[16] G. F. Kunz. *Mineral. Ind.*, **16**, 792, (1907).

[17] A. Lacroix. Mineralogie de la France et ses Colonies, **IV**, 893.

Table II. Effect of Radium Radiation on Rose Quartz

A—Radiation with 230 mg. radium.

Spec. no.	Color class	Original Specimens		Heat-decolorized Specimens	
		Time of treatment	Result	Time of treatment	Result
30	i	7 days	Dark smoky color	7 days	Dark smoky color
12a	ii	147 hrs.	Smoky color not quite masking original color	147 hrs.	Strong black smoky color
9	iii	147 hrs.	Deep black smoky, completely masking original color	147 hrs.	Deep black smoky
1	iii	168 hrs.	Dark smoky	168 hrs.	Dark smoky
8	iv	168 hrs.	Dark smoky	168 hrs.	Dark smoky
20	v	168 hrs.	Dark smoky	168 hrs.	Dark smoky
21a	v	170 hrs.	Dark smoky	170 hrs.	Moderate dark smoky
16	vi	170 hrs.	Dark smoky	170 hrs.	Dark smoky
7	vi	170 hrs.	Fairly dark smoky	170 hrs.	Very dark smoky
28	vi	171 hrs.	Dark smoky	171 hrs.	Slight smoky
14	vii	171 hrs.	Dark smoky	171 hrs.	Dark smoky
11	viii	171 hrs.	Rapidly developed dark smoky	171 hrs.	Rapidly developed dark smoky
18	ix	166 hrs.	Dark smoky	166 hrs.	Moderate smoky
10	ix	166 hrs.	Very dark smoky	166 hrs.	Dark smoky
17	ix	166 hrs.	Very dark smoky	166 hrs.	Dark smoky
13	ix	195 hrs.	Dark smoky	195 hrs.	Dark smoky
19	x	195 hrs.	Dark smoky	195 hrs.	Dark smoky
24	x	195 hrs.	Light smoky	195 hrs.	Light smoky
(2nd expt.)		172 hrs.	Dark smoky	172 hrs.	Dark smoky
2	xi	172 hrs.	Slight smoky	172 hrs.	Light smoky
(2nd expt.)		167 hrs.	Fairly dark smoky	167 hrs.	Fairly dark smoky
23	xii	172 hrs.	Slight smoky	172 hrs.	Dark smoky
(2nd expt.)		167 hrs.	Dark smoky	—	—
12b	xiii	190 hrs.	Moderate dark smoky	190 hrs.	Dark smoky
21b	xiii	190 hrs.	Moderate smoky	190 hrs.	Moderate smoky
6	xiii	167 hrs.	Very slight change	167 hrs.	Very slight change
(2nd expt.)		190 hrs.	No further change	190 hrs.	No further change
27	xiii	167 hrs.	Very dark smoky	167 hrs.	Dark smoky

B—Radiation by being sealed in a tube 6 mm. in diameter and 40 mm. long, into which 125 millicuries of radium emanation were introduced. All of the specimens fluoresced an orange yellow, quite similar to the fluorescence of many calcites under such radiations. The tube was opened three weeks later, when 98% of the emanation had decomposed.

Spec. no.	Color class	Original Specimens Result	Heat-decolorized Specimens Result
12a	ii	Smoky black	Smoky black
1	iii	Smoky black	Smoky black
21a	v	Smoky black	Smoky black
7	vi	Smoky black	Smoky black
18	ix	Smoky black	Smoky black
23	xii	Smoky black	Smoky black
6	xiii	Practically no effect	Practically no effect

The conclusion from these experiments is that rose quartz can not owe its color to the action of radioactive substances on white quartz. An added confirmation for this opinion is the fact that in Madagascar rose quartz is never associated with radioactive minerals, while smoky quartz often occurs with them.[18] In Ontario smoky quartz is a constant associate of radioactive minerals.[19] The usual action of radiations on quartz, then, is to produce the smoky color, though it must be noted that amethyst is also reproduced in this way on occasions, due to some difference in the quartz which is radiated. But the rose color has never been so produced.

V. THE IMPURITIES PRESENT IN ROSE QUARTZ

If the color of rose quartz is due to the presence of some finely divided impurity it would be expected that the amount of that particular substance present in the quartz would vary in proportion to the depth of the color. With this in mind, analyses for the oxides of all metals likely to cause such a color were made.

Watson and Beard[20] have published analyses of eight specimens of rose quartz; and they found the following average amounts of impurities: MnO 0.000423%, TiO_2 0.003185, Fe_2O_3 0.0274, and traces of CoO. Since they did not indicate the depth of color of their specimens, no conclusions in regard to the relationship between the amount of the various impurities and the depth of color can be made. Steiger[21] found 0.0002% MnO in rose quartz from Creede, Colo.

The method used for the analysis of rose quartz was suggested to the writer by Watson and Beard's procedure. It differs from their method in several minor features. The procedure outlined below is thought to be both accurate and relatively rapid.

The quartz fragments are ground as finely as possible in an agate mortar.[22] A weighed portion is transferred to a platinum

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[18] A. Lacroix. Minéralogie de Madagascar, **II,** 260. (Paris, 1922).

[19] H. V. Ellsworth. *Summ. Rept. Geol. Surv. Canada,* **(1922),** pt. D, 51-70.

[20] T. L. Watson and R. E. Beard. *Proc. U. S. Nat. Museum,* **53,** 553-63, (1917).

[21] Statement included in Watson and Beard's paper.

[22] If an iron mortar is used for the grinding, it is absolutely impossible to remove all the iron filings by magnets, large or small. If leaching with dilute acid is resorted to, part of the iron from the quartz itself may be removed, as it is to a large extent soluble in acids. The impurities introduced from the agate mortar are inconsiderable, being nearly pure silica, and extremely small in amount.

crucible, and thoroughly moistened with H_2SO_4, and HF added. The silica is volatilized by gently heating the crucible in an air bath or on a hot plate. Portions of HF are added from time to time to replace that driven off.[23] When the SiO_2 has been volatilized, evaporation is continued until fumes of SO_3 appear. The solution is then washed into a porcelain casserole, evaporated, and the residue is fused with $KHSO_4$.[24] This fusion is dissolved in 5% H_2SO_4, and aliquot parts of the solution are used for the several determinations to be made. Iron is most easily and accurately determined by titration with a weak permanganate solution. Manganese is oxidized to the permanganate by a minute's boiling with a gram of KIO_4, and colorimetrically determined. Titanium is estimated by the usual colorimetric method, with H_2O_2. A two gram sample was used in the determination of each of these metals, and the analyses were made in duplicate. In addition, loss on ignition (mostly water or CO_2 present as inclusions), and the total amount of solid impurities were determined, as well as Al_2O_3, CoO, and Li_2O on certain specimens. Loss on ignition results may be somewhat high, due to the fact that the fine powder may have adsorbed moisture. Aluminum was precipitated as the hydroxide, and the precipitate purified by treatment with HF. Co was precipitated as the sulfide, and the precipitate gathered in a borax bead, whose color was compared with that of standard beads containing known amounts of CoO.[25] The Li was separated from other alkalies, and the flame given by a drop of the concentrated solution, on a platinum wire, observed through a Merwin screen, was compared with the flame from a drop of standard solution.

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[23] The silica may be volatilized in a wax beaker by treatment with HF and H_2SO_4 for about a week. The procedure is then the same as for the solution from the crucible.

[24] The evaporation and fusion may be carried through in the platinum crucible, but there are these disadvantages: (1) There is a loss of platinum from the crucible. (2) The $KHSO_4$ fusion is difficult to remove from the crucible, and must later be transferred to another dish to be dissolved.

[25] The standard borax beads averaged 0.025 g. in weight. Their colors and the amount of CoO they contained were:

5×10^{-6} gs. CoO	Very pale blue (Ridgway 49 f-g)
1×10^{-5}	Pale blue (50 f)
2.5×10^{-5}	Blue (51 d)
5×10^{-3}	Dark blue (53 a)
1×10^{-4}	Very dark blue (53 j)

In table III are given the results of the analyses. The percentages of Mn, Ti, and Fe are stated in terms of MnO, TiO_2, and Fe_2O_3, but this must not be taken to indicate that those are necessarily the valence states of the metals in the quartz. The specimens are arranged in the order of the depth of color, passing from class i, deep rose, to xiii, white.

Table III. Analyses of Rose Quartz

Color class	Spec. no.	MnO	TiO_2	Fe_2O_3	CoO	Li_2O	Al_2O_3	Loss on ignition	Total solid impurities	Total impurities
i	30	0.0005%	0.004+%	0.016%	—	—	—	0.10%	0.25%	0.35%
ii	12a	.0006	.003	.008	0.0001%	0.00x%	—	.19	.22	.41
iii	1	.0005	.004	.022	.0000+	.0x–.00x	—	.23	.26	.49
iii	9	.0002+	.003	.006	—	—	—	.25	.29	.54
iv	8	.0003	.004	.010	—	—	—	.13	.19	.32
v	20	.0004	.003	.007	.0001	.00x	.06	.15	.22	.37
v	21a	.0004	.006	.007	—	—	—	.20	.17	.37
vi	16	.0003	.003	.012	—	—	—	.17	.13	.30
vi	7	.0002+	.002+	.006	.0000+	—	.16	.17	.29	.46
vi	28	.0002	.003	.006	—	—	—	.15	.23	.38
vii	14	.0002+	.003+	.006	—	—	—	.15	.20	.35
viii	11	.0002+	.003	.006	.0000+	.0x–.00x	.12	.13	.18	.31
ix	18	.0002	.003	.008	—	—	—	.21	.17	.38
ix	10	.0001+	.003+	.005	—	—	—	.12	.28	.40
ix	17	.0002+	.003	.007	—	—	—	.21	.18	.39
ix	13	.0003	.003	.007	—	—	—	.19	.27	.46
x	19	.0002	.003+	.004	—	—	—	.17	.21	.38
x	24	.0002+	.003	.013	—	—	—	.16	.17	.33
xi	2	.0002	.003	.006	.0001	.0x–.00x	.12	.17	.20	.37
xii	23	.0002+	.002+	.012	—	—	—	.18	.20	.38
xii	3	.0002	.003	.012	—	—	—	—	—	—
xiii	12b	.0005	.003	.008	.0001	.00x	.13	.14	.21	.35
xiii	4	.0002+	.005	—	—	—	—	—	—	—
xiii	21b	.0003+	.006	.007	—	—	—	.16	.15	.31
xiii	6	.0002	.003	—	—	—	—	.19	.20	.39
xiii	27	.0003+	.003	.008	none	.00x	.12	—	—	—
xiii	26	.0002+	.003+	—	—	—	—	—	—	—

+ = approximately ½ unity in the corresponding decimal place. e.g. .0002+ = .00025.

Gold was tested for in 15 g. samples of three specimens (12a, 1, and 11), with negative results. Negative tests were also obtained for U, Cr, and Ce on 40, 20, and 35 g. composite samples, respectively.

The percentages for MnO and TiO_2 are very close to those reported by Watson and Beard. Iron in the writer's analyses averaged somewhat lower than their results. This may be due to the fact that they ground their specimens in an iron mortar, and the removal of the iron afterwards by leaching with dilute acid may not have been complete.

A microscopic examination was made of all the specimens. The fragments were immersed in clove oil. In every case very long and slender needles of rutile were observed, but in small amounts; and liquid or gaseous inclusions, more abundantly. These observations are in exact agreement with those of Watson and Beard. Apparently the presence of rutile inclusions in rose quartz is universal. Limonite stains are macroscopically visible on many specimens.

Non-gaseous carbon compounds were searched for with negative results. The amount present, if any, is so small as to escape detection. Five gram samples of two of the most deeply colored specimens, 12a and 1, were leached successively with hot water for 3 hrs., hot dilute HNO_3 for 10 hrs., and hot concentrated H_2SO_4 for 6 hrs. Each filtrate was boiled down, but none of them yielded a residue containing material of a carbonaceous nature.

We may now consider the theories which have been proposed to account for the color of rose quartz, in their relation to the various impurities found to be present. The color has been ascribed to (1) manganese compounds, (2) titanium compounds, (3) carbon compounds and (4) to the action of radioactive substances on white quartz (see part IV). Rose quartz colored by inclusions of pink dumortierite, from Nevada, and by manganese silicate inclusions, from Sweden, have been previously mentioned. The true rose quartz, however, contains no inclusions of microscopic size to which the color might be due.

Hermann[26] suggests that the color of rose quartz may be due to a manganese compound, present in solid solution or as sub-microscopic particles. Many text-books mention this as a probability. Fuchs[27] found 1.0–1.5% TiO_2 in rose quartz from Rabenstein. Weinschenk[28] strongly questions this result, for he was able to find only a trace of titanium on a 25 gram sample from that locality. He believes, however, that the color may be due to very small amounts of sesquioxides of Ti, Sn, or Zr. He has shown by experiments on pure synthetic corundum that a red coloration may be given by titanium. In his paper "Colloids in geologic problems" Hubbard[29] makes the simple statement: ". . . rose

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[26] W. Hermann. *Z. anorg. Chem.*, **60**, 369-404, (1908).
[27] J. N. Fuchs. *J. Chemie Physik*, **62**, 253-9, (1831).
[28] E. Weinschenk. *Z. anorg. Chem.*, **12**, 375-92, (1896).
[29] Geo. D. Hubbard. *Amer. J. Sci.*, **4**, 95-110, (1922).

quartz owes its color to the absorption of colloidal Ti on its particles as they came together to build up the crystal. . . ." No authority is quoted.

Berthier[30] thought rose quartz contained an organic pigment. Carbon compounds were proposed by Kraatz Koschlau and Wöhler[31] to account for the color of amethyst and smoky quartz because those minerals were found to contain small amounts of CO_2 and H_2O. On the same basis such a theory might as well be extended to rose quartz. Weinschenk[32] vigorously opposed this idea, for though he granted the presence of C and H in quartz, he doubted very much that they were in such a combination as to produce the colors observed, since coloring matters are the exception rather than the rule among hydrocarbons. Such pigments are not members of the mineral kingdom. Watson and Beard[33] concluded that rose quartz was colored by an organic compound, ". . . the writers conclude that the color of rose quartz can not be attributed to an inorganic substance. . . ." They did not consider the inorganic impurities as capable of causing the color, and since the color of heat decolorized specimens was not restored by exposure to sunlight or radium radiations, they came to the conclusion that the pigment was organic. But the fact that the color was not thus restored does not necessarily imply an organic coloration. Such chemical reactions as oxidation, reduction, dehydration or loss of CO_2 from carbonates might easily account for the destruction of an allochromatic color by heat, and the color so destroyed would not be expected to return on the application of radiations. Since no carbon compounds were found by the writer in the most deeply colored specimens of rose quartz, this theory of the color will be dismissed, especially since no positive proof of the theory has ever been advanced.

An examination of the analyses in table III shows that the amount of iron bears no relation to the depth of color. It must be present largely, if not wholly, as limonitic stains, which penetrate the crevices of the mineral. The amount of TiO_2 is very uniform

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[30] *Ann. Mines*, [?], **10,** 272; **13,** 218; reference from Rammelsberg's Mineralchemie. Series number and year not given; probably 1st or 2nd series, 1816–31.

[31] K. V. Kraatz Koschlau and Lotha Wöhler. *Minn. petr. Mitt.*, **18,** 304–33, (1898).

[32] E. Weinschenk. *Minn. petr. Mitt.*, **19,** 144–7, (1899).

[33] T. L. Watson and R. E. Beard. *Proc. U. S. Nat. Museum*, **53,** 553–63, (1917).

in all specimens from deep rose to white and it is undoubtedly to be accounted for by the observed rutile inclusions. It is interesting to note that specimens 21a and 21b, rose and white, which contained the highest amount of titanium, were decidedly bluish in tinge. This accords with a previous note by the writer,[34] in which attention is called to a rose quartz with abundant rutile inclusions, which had a more than usual bluish color as a result. Except in this indirect way, the TiO_2 in rose quartz can have no influence upon its color. In most specimens the amount is so small that even the effect of the rutile inclusions in imparting a slightly bluish tinge must be nearly *nil.* Cobalt is present in such small amount as to be hardly considered as a pigment. Of the coloring elements known to occur in rose quartz, only manganese is left. Table IV gives the average percentages of MnO for the quartz specimens arranged in groups by their color, classes i to xiii, and for the larger divisions based on the grades of Ridgway's color scales. From this table as well as from an examination of Table III it is apparent that the amount of MnO in rose quartz does vary with the color, for it is most abundant in the deeper colored specimens, and decreases in the paler ones. While the MnO content increases in general with the depth of color of the rose quartz specimens, it must be noted that the six white specimens have somewhat more manganese than the palest specimens of rose quartz. This is interpreted by the writer as being due to temperature conditions prevailing at the time of formation of the quartz. Bastin[35] states in speaking of the coarser Maine pegmatites "the portions characterized by high and by low temperature quartz" (formed above and below 575°) "are . . . intimately associated in the same pegmatite mass." Heating to above 575° causes the decolorization of rose quartz (see part VIII of this paper). It is very reasonable to assume that a temperature above 575° would prohibit the production of the rose color, even though the potential pigment material was present. The balance of temperature above or below that point in coarse pegmatites is so delicate that one part of the mass could receive a color, while in a neighboring part the temperature would be high enough to keep the color from developing, even though this part contained as much of the coloring ingredient. At the same time, if the color were produced, it

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[34] Edw. F. Holden. *Amer. Mineral.*, **8,** 117-21, (1923).

[35] E. S. Bastin. *U. S. Geol. Survey Bull.*, **445,** 39, (1911).

would vary in intensity with the amount of pigment. This, the writer believes, explains the observed relations between the MnO content and the depth of color.

TABLE IV. RELATION BETWEEN MnO CONTENT AND THE DEPTH OF COLOR IN ROSE QUARTZ

COLOR CLASS	NUMBER OF ANALYSES	AVERAGE % MnO	RIDGWAY'S COLOR CLASS	NUMBER OF ANALYSES	AVERAGE % MnO
Deep rose i	1	0.0005	67″ d-e	5	0.0004+
ii	1	.0006			
iii	2	.0004			
iv	1	.0003			
Rose v	2	.0004	67″ f	5	.0003
vi	3	.0002+			
Pale rose vii	1	.0002+	67″g or paler	11	.0002
viii	1	.0002+			
ix	4	.0002			
x	2	.0002			
xi	1	.0002			
xii	2	.0002			
White xiii	6	.0003	White	6	.0003

There is no impurity visible microscopically to account for the Mn. The conclusion is justified from the analyses that the color of rose quartz is due to some compound of manganese. The valence must be determined from criteria given later.

(*To be continued*)

CENTRALLASITE FROM CRESTMORE, CALIFORNIA

WILLIAM F. FOSHAG,[1] *United States National Museum*

During the winter of 1921 the writer collected in the Wet Weather Quarry of the Riverside Portland Cement Company, at Crestmore near Riverside, California, a number of specimens of an unusual pegmatite. The pegmatite vein itself could not be located in the quarry face but the blocks on the quarry floor carried pegmatite cutting across limestone as well as contact rock. The veins were made up largely of feldspar with wollastonite, orange colored prehnite and massive greenish datolite. The

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