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Crystal chemistry of the serandite—pectolite series and related minerals

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Abstract

The serandite structure has been refined to R = 3.0 percent, using a crystal from Tanohata mine, Japan (approximately 39.9°N, 141.9°E), $P\bar{1}$, a 7.683(1), b 6.889(1), c 6.747(1) Å, α 90.53(5)°, β 94.12(2)°, γ 102.75(2)°, $Z = 2 \times [(Mn_{1.88}Ca_{0.17}Mg_{0.01})Na_{1.00}HSi_{2.97}O_9]$. The noteworthy features of the structure of serandite which is isotypic to pectolite include: (1) Almost all Si–O and all Na–O lengths are smaller than the corresponding lengths in pectolite: the mean values are 1.623(2)[1.630(2)] Å and 2.485(1)[2.580(1)] Å respectively (values in brackets are those for pectolite). (2) A comparison of the serandite and pectolite structures suggests that the shrinkage of octahedral bands due to substitution of Mn for Ca gives rise to distortions of individual silicate tetrahedra rather than a change in configuration of silicate chains. (3) Ca atoms are preferably located at the M(1) position which corresponds to Ca(1) in the pectolite structure; the occupany at M(1) is 0.84(1) Mn and 0.16(1)Ca.

The specific mode of cation ordering has been interpreted based on the following geometrical considerations: (1) the relations between the configuration of Si_3O_9 chains and the size of cation octahedra; and (2) the location of silicate chains relative to octahedral bands. Rules brought out from these considerations may be used to explain the modes of cation ordering in the wollastonite-group minerals in general.

Introduction

The pectolite ($Ca_2NaHSi_3O_9$)-serandite ($Mn_2NaHSi_3O_9$) series is of particular interest because it provides a rare example of solid solution in silicate minerals where the substitution of Mn for Ca extends over the whole range of the series while the structure type remains unchanged (Schaller, 1955). None of the structures of minerals in this series have been investigated except that of pectolite, which was determined by Buerger (1956) and refined by Prewitt and Buerger (1963) and further by Prewitt (1967). We have therefore carried out a structural study of serandite to elucidate the crystal chemical nature of the series. That part of the study concerning the procedure of structure analysis has been reported separately (Takéuchi *et al.*, 1973) as an example of application of the partial Patterson method (Takéuchi, 1972a). A brief account on the hydrogen-bonded system of serandite has also appeared (Takéuchi and Kudoh, 1972). The present paper reports the details of the structure and offers a crystal chemical discussion on the pectolite–serandite series and related minerals such as wollastonite and bustamite. Though crystal chemical aspects of the wollastonite group minerals were discussed by Prewitt and Buerger (1963), Peacor and Prewitt (1963), and by Prewitt and Peacor (1964), a different approach is provided in the present paper.

Experimental

Well developed serandite crystals (up to 10 cm long and several cm wide on cleaved faces) from the Tanohata mine were used in the present study. Electron microprobe analyses (Table 1) revealed that the chemical composition of the specimens was close to that of the Mn end-member of the serandite–pectolite series, giving a formula of:

$$(Mn_{1.88}Ca_{0.17}Mg_{0.01})Na_{1.00}HSi_{2.97}O_9.$$

The cell dimensions, which were determined with a four-circle diffractometer (Mo$K\alpha$ = 0.70926 Å), are compared in Table 2 with those of pectolite (Prewitt, 1967). The unit cell contains two of the above chemical units. Space group $P\bar{1}$ was assumed on the basis of the triclinic diffraction symmetry and the results of an $N(z)$ test (Howells *et al.*, 1950) which showed the existence of a center of symmetry.

K	FO	FC
H,L=	-2	-9
1	11	-12
2	11	-12
H,L=	-1	-9
3	10	-11
H,L=	0	-9
1	6	-5
2	26	28
H,L=	1	-9
2	25	28
H,L=	2	-9
1	10	11
2	6	-7
H,L=	-5	-8
1	11	-12
2	35	39
H,L=	-4	-8
1	9	8
2	14	-15
4	39	43
H,L=	-3	-8
2	30	-32
3	15	-16
4	14	-13
H,L=	-2	-8
1	14	-16
2	40	-43
3	9	10
4	22	-23
5	18	-20
H,L=	-1	-8
1	16	18
2	20	21
3	7	7
4	32	-34
5	11	13
H,L=	0	-8
1	7	-8
2	25	27
3	5	6

K	FO	FC
4	14	14
H,L=	1	-8
1	9	9
2	14	15
3	8	-10
4	27	29
5	14	14
H,L=	2	-8
1	19	-20
2	15	-14
3	10	11
4	16	18
H,L=	3	-8
1	12	12
2	22	-24
3	21	-23
H,L=	4	-8
1	6	-7
2	7	-8
3	13	15
H,L=	5	-8
1	8	8
2	18	-20
H,L=	-6	-7
1	7	7
2	30	31
3	17	-18
4	6	7
H,L=	-5	-7
2	19	20
4	16	17
5	14	-15
H,L=	-4	-7
1	9	9
2	14	-15
3	10	11
4	25	26
H,L=	-3	-7
2	8	-9
3	5	5

K	FO	FC
4	6	6
6	22	24
H,L=	-2	-7
2	24	-26
3	4	5
4	6	5
5	13	13
6	17	18
H,L=	-1	-7
1	7	-8
2	29	-30
3	10	-11
4	15	-17
6	24	27
H,L=	0	-7
2	19	-21
3	13	-14
4	30	-32
5	11	-12
6	15	-17
H,L=	1	-7
2	20	21
3	12	14
4	32	-33
6	27	-30
H,L=	2	-7
2	36	39
3	9	10
4	13	15
6	21	-22
H,L=	3	-7
1	14	15
2	26	28
3	4	-5
4	30	33
5	20	23
H,L=	4	-7
1	17	-18
2	27	-29
4	25	27

K	FO	FC
5	7	-6
H,L=	5	-7
2	33	-36
3	8	-9
4	22	-25
H,L=	6	-7
2	13	-15
H,L=	-7	-6
2	46	-50
H,L=	-6	-6
1	7	8
2	15	-16
3	19	-20
4	40	-44
H,L=	-5	-6
1	11	-11
3	21	24
4	13	-15
6	33	-36
H,L=	-4	-6
1	10	11
2	48	52
3	11	-12
4	20	21
5	13	15
6	7	-7
H,L=	-3	-6
1	6	-4
2	32	34
4	37	40
5	9	-10
6	25	27
7	27	29
H,L=	-2	-6
1	16	19
2	47	-50
3	18	-19
4	22	24
5	10	11
6	34	37

K	FO	FC
7	12	-12
H,L=	-1	-6
1	28	-29
2	56	-59
3	23	25
4	38	-41
5	30	-33
6	16	17
7	4	-5
H,L=	0	-6
1	24	25
2	33	-35
4	42	-46
5	15	17
6	34	-36
7	11	-11
H,L=	1	-6
1	17	-19
2	46	48
4	35	-37
5	11	13
6	8	-7
H,L=	2	-6
1	7	-3
2	27	28
4	31	34
6	30	-33
H,L=	3	-6
1	11	12
2	40	43
3	10	-10
4	8	7
6	10	10
H,L=	4	-6
1	6	-8
2	10	-10
4	15	17
5	14	-14
H,L=	5	-6
1	13	14

K	FO	FC
5	12	12
H,L=	6	-6
1	12	-12
2	15	-16
3	6	5
4	10	11
H,L=	7	-6
1	13	14
2	9	-8
3	11	-12
H,L=	8	-6
1	13	-13
H,L=	-8	-5
2	24	-26
H,L=	-7	-5
2	54	-56
4	6	-7
5	15	-16
6	15	17
H,L=	-6	-5
1	6	4
2	5	-2
3	11	11
4	40	-43
6	6	-7
H,L=	-5	-5
2	10	11
3	5	4
4	23	-24
5	11	10
6	17	-18
7	14	14
H,L=	-4	-5
2	22	22
3	9	-9
6	20	-22
H,L=	-3	-5
2	6	6
3	11	10
4	15	15

K	FO	FC
6	19	-20
8	18	-18
H,L=	-2	-5
1	5	-3
2	18	20
3	13	-14
4	9	10
6	13	15
7	17	-17
8	7	-8
H,L=	-1	-5
2	9	6
3	13	12
4	17	18
6	16	17
7	16	17
H,L=	0	-5
1	13	14
3	17	-17
2	19	-19
5	11	8
6	23	24
7	9	10
8	29	30
H,L=	1	-5
2	27	-27
4	35	-37
5	16	-16
H,L=	2	-5
2	12	-11
3	21	23
4	37	-37
6	43	-46
7	15	-16
H,L=	3	-5
1	6	-7
2	51	53
4	6	-8
6	30	-30
H,L=	4	-5

K	FO	FC
0	22	22
1	9	9
2	57	57
3	8	-10
4	46	48
5	24	25
6	9	-10
H,L=	5	-5
1	15	-15
2	12	12
4	51	53
6	35	37
H,L=	6	-5
1	13	14
2	38	-39
3	9	-8
4	11	11
5	17	-17
H,L=	7	-5
1	10	9
2	37	-39
4	36	-38
H,L=	8	-5
1	12	-12
2	18	-18
3	8	8
H,L=	-9	-4
1	15	18
2	18	18
3	6	-7
H,L=	-8	-4
1	9	-8
2	8	8
3	24	25
4	12	13
H,L=	-7	-4
1	13	13
H,L=	-8	-4
5	6	-4
H,L=	-7	-4

K	FO	FC
4	23	24
5	23	24
6	13	13
H,L=	-6	-4
1	17	-17
2	30	-32
3	10	9
4	8	-7
6	34	35
7	25	27
H,L=	-5	-4
1	9	11
2	51	-53
3	41	-44
4	34	-35
5	7	-8
6	6	3
7	21	-22
8	36	38
H,L=	-4	-4
1	16	-17
2	11	12
3	25	26
4	66	-69
5	22	-21
6	31	-32
7	15	-18
H,L=	-3	-4
1	17	17
2	51	53
3	7	7
6	65	-68
H,L=	-2	-4
1	14	13
2	123	129
4	20	19
5	26	27
7	11	13
8	53	-54
H,L=	-1	-4

K	FO	FC
1	20	-19
2	31	-31
3	17	18
4	95	98
6	11	11
7	19	20
8	12	-12
H,L=	0	-4
2	32	-32
3	31	-31
4	8	10
5	14	-15
6	44	45
7	16	-16
8	14	15
H,L=	1	-4
1	5	-5
2	58	-59
3	15	15
4	36	-36
5	19	-19
6	9	9
8	18	19
H,L=	2	-4
1	17	17
2	5	-5
3	25	-25
4	34	-35
5	21	21
7	17	-17
8	9	10
H,L=	3	-4
1	12	-14
2	40	40
3	31	30
5	14	-14
6	29	-30
7	22	23
H,L=	4	-4
1	34	34

K	FO	FC
2	25	26
3	8	-9
4	22	22
5	18	18
6	15	-15
7	8	-6
H,L=	5	-4
1	30	-31
2	11	12
3	13	13
4	9	10
5	15	-17
6	14	14
H,L=	6	-4
1	8	9
2	24	-26
3	5	-5
4	27	30
5	11	11
H,L=	7	-4
1	12	-12
3	9	-9
5	5	4
H,L=	8	-4
2	32	-35
3	5	1
H,L=	9	-4
1	11	12
2	10	-11
H,L=	-10	-3
2	18	-18
H,L=	-9	-3
1	5	4
2	29	31
3	7	9
4	13	-13
5	19	20
H,L=	-8	-3
2	53	57
3	7	-7

K	FO	FC
4	19	21
5	4	-5
6	5	-5
7	19	20
H,L=	-7	-3
1	6	7
2	8	9
3	15	-15
4	34	36
6	20	21
H,L=	-6	-3
1	7	-8
2	36	-38
4	13	15
5	26	-28
6	18	20
7	10	-10
8	19	20
H,L=	-5	-3
1	14	14
2	19	-20
3	17	19
4	31	-33
5	10	9
6	6	-5
7	16	-17
8	18	19
H,L=	-4	-3
1	7	-8
2	14	-14
3	18	19
4	35	-37
5	21	23
6	5	-5
7	14	15
9	10	-10
H,L=	-3	-3
1	10	-11
2	21	21
3	27	-28

K	FO	FC
4	7	7
5	4	5
6	32	-34
7	6	7
8	4	2
9	8	9
H,L=	-2	-3
2	58	57
3	8	-9
4	4	3
5	7	-7
6	14	-15
8	25	-28
H,L=	-1	-3
1	5	-6
2	38	39
3	9	-10
4	31	33
5	21	-22
6	7	-6
7	12	-12
8	13	-15
9	11	-12
H,L=	0	-3
1	26	24
2	32	32
3	24	22
4	40	42
5	5	6
6	7	6
7	7	6
8	23	-25
9	5	-7
H,L=	1	-3
1	12	13
2	32	-33
3	5	4
4	41	43
5	24	25
6	35	37

K	FO	FC
7	15	16
8	8	8
H,L=	2	-3
1	28	-27
2	68	-73
3	7	-7
5	7	-7
6	37	39
8	18	19
H,L=	3	-3
2	73	-75
3	8	11
4	35	-38
5	18	-20
6	7	-7
7	5	-6
8	25	28
H,L=	4	-3
2	11	12
3	19	-21
4	53	-57
6	14	-15
7	19	-21
H,L=	5	-3
2	42	44
3	13	14
5	12	13
6	29	-31
H,L=	6	-3
2	37	40
3	5	6
4	40	44
5	11	12
H,L=	7	-3
2	5	-5
4	19	20
5	10	-10
H,L=	8	-3
2	42	-47
3	6	-7

K	FO	FC
4	11	-11
H,L= 9 -3		
1	19	-20
2	26	-29
H,L=-10 -2		
2	7	-6
4	13	-14
H,L= -9 -2		
1	16	-17
2	11	11
3	7	-6
4	21	-22
5	14	-15
6	13	-13
H,L= -8 -2		
1	11	11
2	6	7
3	5	-5
6	43	-46
7	15	-17
H,L= -7 -2		
2	38	40
3	17	18
4	4	-5
5	5	5
6	4	-5
7	11	-12
8	39	-42
H,L= -6 -2		
1	4	3
2	21	22
3	8	8
4	64	69
5	8	8
6	10	-11
7	14	14
H,L= -5 -2		
1	8	8
2	30	31
3	20	-20

K	FO	FC
4	23	24
5	26	27
6	59	62
7	16	17
8	5	-3
9	13	14
H,L= -4 -2		
1	32	-31
2	80	-84
3	17	-16
4	17	18
5	39	-41
6	35	38
7	9	10
8	33	36
9	13	13
H,L= -3 -2		
1	29	29
2	58	-59
3	4	4
4	53	-56
5	5	-5
6	20	-22
7	33	-35
8	19	21
9	12	14
H,L= -2 -2		
1	16	-18
3	50	52
4	58	-61
5	12	-13
6	41	-44
9	31	-33
H,L= -1 -2		
1	34	34
2	78	81
3	30	-30
4	18	19
5	51	54
6	31	-33

K	FO	FC
7	7	-9
8	38	-42
H,L= 0 -2		
1	61	-61
2	31	36
3	27	27
4	84	88
6	22	23
7	33	34
8	33	-35
H,L= 1 -2		
1	15	17
2	27	-28
3	62	-64
4	60	64
5	15	-17
6	40	43
8	26	26
9	16	18
H,L= 2 -2		
1	9	8
2	51	-52
3	16	16
4	54	-56
5	23	-24
6	52	55
7	6	-6
8	5	6
H,L= 3 -2		
1	10	11
2	105	-111
3	8	9
4	21	-21
6	15	-16
7	8	-8
8	37	39
H,L= 4 -2		
2	35	36
3	9	9
4	52	-55

K	FO	FC
5	12	14
6	15	-15
H,L= 5 -2		
1	11	-12
2	4	5
3	15	17
4	5	6
6	23	-24
7	9	9
H,L= 6 -2		
2	30	32
3	23	-25
H,L= 7 -2		
1	10	-10
2	8	9
3	9	9
4	10	10
H,L= 8 -2		
1	7	9
2	11	12
3	15	-17
4	11	11
H,L= 9 -2		
1	8	-9
2	4	-4
3	13	14
H,L= 10 -2		
1	21	22
H,L=-10 -1		
2	37	-40
3	19	-20
4	8	-8
H,L= -9 -1		
2	27	-29
3	4	4
4	28	-29
5	15	-16
6	7	-8
H,L= -8 -1		
1	6	5

K	FO	FC
2	16	16
3	10	11
4	23	-25
5	10	11
6	36	-37
7	6	-8
H,L= -7 -1		
1	5	-5
2	74	79
6	12	-13
7	14	15
8	28	-30
H,L= -6 -1		
2	21	21
4	69	73
5	13	14
6	12	-14
7	15	16
8	31	-32
H,L= -5 -1		
1	8	-7
2	23	-23
3	10	-11
4	42	44
5	10	-10
6	33	35
7	7	-8
8	11	-11
9	15	16
H,L= -4 -1		
1	3	4
2	55	-56
3	14	13
4	4	-1
5	14	-16
6	35	37
7	7	-8
8	8	8
9	11	-11
H,L= -3 -1		

K	FO	FC
1	11	12
2	87	-89
3	6	-6
4	25	-25
5	22	23
6	33	36
8	23	24
9	11	-12
H,L= -2 -1		
1	15	-15
2	9	-9
3	32	-30
4	31	-34
5	9	-10
7	13	13
8	32	36
H,L= -1 -1		
1	11	9
2	15	16
3	15	15
4	44	-46
6	19	-22
9	18	19
H,L= 0 -1		
2	9	-6
3	15	15
4	13	-13
5	26	-25
6	31	-33
7	5	-5
8	8	-9
9	8	-9
H,L= 1 -1		
1	25	24
2	55	56
3	13	13
4	10	10
5	19	19
6	25	-26
7	12	-13

K	FO	FC
8	25	-26
9	9	-9
H,L= 2 -1		
1	25	-23
2	7	8
3	5	4
4	40	40
5	28	29
6	31	34
7	14	14
8	17	-18
H,L= 3 -1		
1	29	-27
2	32	-34
3	31	-30
4	35	37
5	7	-7
6	33	35
7	11	11
8	25	27
H,L= 4 -1		
1	15	16
2	46	-48
4	37	-39
5	22	-23
6	17	19
7	4	5
H,L= 5 -1		
1	18	17
2	27	-28
3	14	-14
4	63	-66
5	8	-9
6	15	-17
7	18	-19
H,L= 6 -1		
2	30	32
3	24	25
4	27	-29
5	6	6

K	FO	FC
6	46	-49
H,L=	7	-1
2	54	59
3	10	11
4	31	34
5	14	15
H,L=	8	-1
1	5	-6
2	41	43
3	12	-13
4	30	32
H,L=	9	-1
2	28	-31
3	5	-4
H,L=	-10	0
1	4	2
2	11	10
3	7	9
H,L=	-9	0
1	5	-5
2	35	-36
3	19	21
4	11	12
5	13	14
6	5	6
7	19	20
H,L=	-8	0
2	13	-13
3	27	-27
4	22	-25
5	19	19
6	10	10
H,L=	-7	0
1	22	-23
2	18	-19
3	5	5
4	21	-22
5	24	-26
6	16	-17
7	7	7

K	FO	FC
8	7	-8
H,L=	-6	0
1	28	29
2	5	4
3	24	-25
4	10	-11
5	4	3
6	22	-23
7	27	-29
8	9	-10
9	7	-7
H,L=	-5	0
1	12	-14
2	71	74
3	26	27
4	22	21
5	22	-24
6	7	-8
7	7	7
8	20	-20
9	25	-27
H,L=	-4	0
1	37	37
2	22	23
3	6	-6
4	56	56
5	45	47
6	26	26
7	13	14
8	6	-8
9	10	10
H,L=	-3	0
1	45	-44
2	73	-74
4	23	22
5	18	-19
6	63	67
7	21	23
8	10	11
9	25	27

K	FO	FC
H,L=	-2	0
1	19	21
4	19	-19
5	13	-13
6	10	-10
7	15	-17
8	49	52
9	17	19
H,L=	-1	0
2	23	-24
3	4	3
5	12	-11
6	13	14
7	23	-24
8	12	12
9	20	-21
H,L=	0	0
2	21	21
3	13	-12
4	22	-21
6	66	-69
7	7	-5
9	27	-29
H,L=	1	0
0	28	27
1	13	12
3	6	4
4	19	16
5	38	40
6	28	-30
7	8	8
8	28	-30
9	8	7
H,L=	2	0
0	45	-45
1	28	-30
2	68	68
3	7	7
4	58	58
5	30	-31

K	FO	FC
6	5	4
7	30	31
8	8	-7
H,L=	3	0
0	88	-96
1	47	47
2	17	-16
3	17	-18
4	14	13
5	7	7
6	22	23
7	14	-15
8	12	-11
H,L=	4	0
0	42	-42
1	35	-35
2	65	-68
3	22	22
5	15	-16
6	10	11
H,L=	5	0
0	33	34
1	15	16
3	23	-23
4	18	-19
5	15	16
6	6	-7
7	14	-15
H,L=	6	0
0	25	26
1	14	-14
2	17	18
3	20	21
4	14	-14
5	8	-8
H,L=	7	0
0	23	25
1	20	21
2	4	5
3	19	-20

K	FO	FC
4	9	10
H,L=	8	0
0	17	-18
2	28	31
3	13	13
4	11	-13
H,L=	9	0
1	5	-6
2	4	-5
3	5	5
H,L=	10	0
0	29	-31
H,L=	-10	1
0	27	-28
1	5	-4
2	27	29
4	22	24
5	12	15
H,L=	-9	1
0	32	-34
1	6	-5
2	40	-42
3	20	-22
4	26	28
5	12	-13
6	37	40
7	14	15
H,L=	-8	1
0	27	-29
2	44	-47
3	15	-16
4	18	-19
5	20	-22
6	20	21
7	25	-27
H,L=	-7	1
0	16	16
2	32	-34
3	32	35
4	56	-59

K	FO	FC
5	12	-13
6	13	-13
7	6	-7
8	26	28
H,L=	-6	1
0	77	82
1	16	16
2	20	20
4	38	-41
5	22	23
6	30	-32
9	7	-6
H,L=	-5	1
0	41	43
1	12	-13
2	42	44
3	9	9
4	23	24
5	26	28
6	34	-36
7	20	21
8	28	-30
H,L=	-4	1
0	38	-38
1	18	-17
2	29	30
3	26	-26
4	35	36
5	9	-10
6	11	12
8	9	-10
9	16	16
H,L=	-3	1
1	12	12
2	11	10
3	11	-14
4	11	12
5	39	-41
6	33	36
7	7	-6

K	FO	FC
8	6	-6
9	10	-11
H,L=	-2	1
0	20	-22
1	35	34
2	56	-56
3	5	7
4	4	-2
5	14	14
6	14	14
7	8	-10
8	28	30
9	10	-10
H,L=	-1	1
0	14	16
1	15	-15
2	10	6
3	9	9
4	44	-46
5	4	3
6	8	8
7	6	7
8	21	23
9	9	8
H,L=	0	1
0	30	31
2	16	-17
3	35	34
4	26	-28
5	9	9
6	33	-35
7	8	9
8	9	8
9	15	17
H,L=	1	1
0	20	22
1	10	-11
2	11	9
3	13	-14
4	23	-23

K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC
5	12	-12	2	71	-76	H,L=	-7	2	1	4	-4	8	28	30	7	9	-11	3	8	-9
6	29	-31	4	23	-25	0	12	13	2	45	45	H,L=	1	2	H,L=	6	2	4	34	37
7	10	-11	5	17	-18	2	34	-36	3	52	51	1	8	-11	0	25	26	6	21	23
8	5	-5	6	15	16	3	21	-22	4	64	66	2	11	-11	1	5	-6	7	17	18
H,L=	2	1	H,L=	7	1	4	7	-7	5	33	35	3	28	29	2	43	-45	H,L=	-7	3
0	72	74	0	37	40	5	14	15	6	27	-29	4	53	-55	5	10	-11	0	49	-52
2	84	87	2	17	-18	6	14	16	7	25	27	5	22	-22	6	7	8	1	5	-5
3	11	-10	3	5	5	7	8	10	8	38	-42	6	33	-35	H,L=	7	2	2	34	-35
4	5	-3	4	28	-30	8	41	44	9	20	-21	7	11	-12	0	8	-7	3	10	-10
5	5	-3	H,L=	8	1	H,L=	-6	2	H,L=	-2	2	8	4	3	1	19	20	4	17	18
6	32	-34	0	35	38	0	13	13	0	79	-86	H,L=	2	2	2	5	-5	5	14	-15
7	15	-16	1	9	-8	1	19	-20	1	7	-6	1	30	29	4	23	-24	6	12	12
8	26	-28	2	30	33	3	9	-8	2	25	27	2	59	60	5	11	12	7	15	-15
H,L=	3	1	3	16	16	4	50	-53	3	51	-51	3	28	27	H,L=	8	2	8	19	19
0	14	13	4	5	-5	5	23	-24	4	78	79	4	10	10	0	19	20	H,L=	-6	3
1	9	-8	H,L=	9	1	6	10	10	5	38	39	5	44	47	1	4	-5	0	25	-28
2	53	54	0	14	16	8	8	9	6	35	38	6	58	-62	2	11	-12	1	6	6
3	7	6	2	33	35	H,L=	-5	2	7	7	8	8	11	-12	3	4	6	2	46	-48
4	43	45	3	12	-11	0	55	57	8	10	-10	H,L=	3	2	4	10	-11	3	23	24
5	22	24	H,L=	10	1	1	13	13	9	26	27	0	38	-36	H,L=	9	2	4	51	-54
6	6	5	0	25	-28	2	31	-31	H,L=	-1	2	1	35	-36	0	10	11	5	11	-11
8	33	-36	H,L=	-10	2	3	5	-3	0	88	-95	2	80	85	1	10	11	6	15	15
H,L=	4	1	0	19	-19	4	20	-20	1	56	-53	3	15	15	2	7	8	7	7	-7
0	48	-50	1	13	-15	5	20	-20	2	28	-32	4	25	25	H,L=	10	2	8	10	10
1	6	-5	3	8	9	6	57	-60	3	6	6	6	12	12	0	16	16	H,L=	-5	3
2	19	20	4	13	14	7	17	-18	4	30	31	7	24	26	H,L=	-10	3	0	79	84
3	9	-9	5	17	-19	8	20	22	5	46	-49	8	35	-36	0	36	39	1	16	17
4	66	70	H,L=	-9	2	9	7	-6	6	39	41	H,L=	4	2	2	27	29	2	19	-20
6	14	16	0	12	-13	H,L=	-4	2	7	20	20	0	24	-24	3	16	17	3	5	-5
7	22	23	1	23	24	0	29	28	8	20	22	1	12	13	4	12	-13	4	37	-38
H,L=	5	1	2	9	-9	1	15	13	9	8	10	2	26	-26	H,L=	-9	3	5	13	14
0	104	-111	4	17	17	2	110	114	H,L=	0	2	3	24	-24	0	19	20	6	29	-30
1	18	18	6	7	8	3	19	19	0	37	-39	4	66	70	1	7	8	7	10	-11
2	22	-22	H,L=	-8	2	4	46	-47	1	58	60	6	5	5	2	47	51	8	17	19
4	5	4	0	16	-17	6	35	-37	2	77	-80	H,L=	5	2	4	22	23	H,L=	-4	3
5	6	-4	2	15	-16	7	26	-27	3	47	-47	0	82	-89	5	16	17	0	65	67
6	35	37	3	25	27	8	32	-34	4	61	-63	1	16	-15	H,L=	-8	3	1	16	-16
7	8	9	5	13	14	9	10	-12	5	9	-10	2	21	-22	0	31	-33	2	76	77
H,L=	6	1	6	28	29	H,L=	-3	2	6	26	29	3	10	-10	1	11	-12	3	4	4
0	19	-19	7	11	12	0	47	49	7	27	-29	6	43	46	2	6	7	4	9	-9

K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC	K	FO	FC
5	27	29	4	9	10	1	15	-17	2	29	31	7	29	-31	3	4	-4	2	11	-11
6	31	-34	5	14	14	2	40	42	4	14	15	8	9	-9	4	65	-69	H,L=	-9	5
7	5	4	6	33	36	3	11	11	5	18	20	H,L=	-2	4	6	5	4	0	21	22
8	18	-19	8	6	7	4	30	32	6	21	23	0	57	57	7	33	-35	2	21	22
9	5	-2	H,L=	1	3	5	8	8	7	12	-13	1	9	-10	H,L=	3	4	3	11	12
H,L=	-3	3	1	8	-7	H,L=	6	3	H,L=	-6	4	2	55	55	0	80	84	4	28	-31
1	23	-24	2	53	-52	0	44	-47	0	8	-9	3	30	30	1	17	-18	H,L=	-8	5
2	68	70	4	6	6	3	6	-6	1	21	-22	4	7	9	2	11	-12	0	36	39
3	6	-6	5	4	5	4	25	26	2	14	-15	5	18	19	3	43	45	2	36	38
4	37	37	6	13	13	5	8	7	3	18	18	6	10	-12	4	29	-30	3	16	17
5	16	-17	7	16	17	H,L=	7	3	4	23	24	7	7	6	5	4	4	4	18	19
6	16	-18	8	16	17	0	27	-30	5	7	-7	8	42	-46	6	35	-38	5	17	17
7	21	22	H,L=	2	3	1	9	-9	6	27	28	H,L=	-1	4	H,L=	4	4	6	28	-31
8	14	-16	0	7	-5	2	49	-54	7	23	26	0	4	4	0	49	51	H,L=	-7	5
H,L=	-2	3	2	29	-29	3	15	-17	8	17	20	2	30	31	1	11	11	0	26	-27
0	47	-47	3	29	-29	H,L=	8	3	H,L=	-5	4	3	28	-29	2	51	54	1	8	-7
1	25	23	4	32	-33	0	19	21	0	31	-32	4	83	86	3	21	-22	2	28	30
2	44	42	5	10	-11	2	33	-36	1	11	12	5	27	29	4	7	-8	3	8	-7
3	21	-22	6	7	7	3	5	-5	2	20	-20	7	11	12	5	20	20	4	37	39
4	47	48	7	7	-7	H,L=	9	3	3	28	-28	H,L=	0	4	6	8	-9	5	32	35
5	18	-19	8	24	25	0	29	32	5	15	15	0	106	-115	H,L=	5	4	6	6	6
6	4	4	H,L=	3	3	2	14	16	6	10	11	1	24	-24	0	19	20	H,L=	-6	5
7	11	-10	0	64	65	H,L=	-10	4	8	17	18	2	35	34	1	15	-17	0	50	-54
8	27	-29	1	8	8	2	8	10	H,L=	-4	4	4	21	21	2	25	28	1	22	-23
9	7	8	2	10	11	H,L=	-9	4	0	29	-29	5	22	-24	4	24	25	2	11	-11
H,L=	-1	3	4	40	-41	0	10	-12	1	29	-29	6	57	61	5	9	-10	3	6	-7
0	106	-111	5	22	-24	1	10	-11	2	48	-50	7	23	25	6	7	-7	4	43	46
1	9	8	6	15	-15	2	26	28	3	20	21	H,L=	1	4	H,L=	6	4	5	19	-20
2	35	-34	7	11	-12	4	7	-8	4	33	-34	0	56	-56	0	36	-39	6	24	25
3	28	28	H,L=	4	3	H,L=	-8	4	5	24	-25	1	27	27	1	11	11	7	15	16
4	33	34	0	31	31	0	12	13	6	13	-14	2	121	-128	3	15	-15	H,L=	-5	5
5	10	11	1	14	13	1	6	7	8	9	10	3	14	-14	4	8	8	0	53	-56
6	15	16	2	16	16	2	5	6	H,L=	-3	4	4	5	5	5	6	6	1	18	19
7	5	-4	3	17	18	3	6	-5	0	48	49	5	19	-20	H,L=	7	4	2	52	-54
8	9	-9	4	6	8	4	30	31	1	31	31	6	24	27	0	8	-9	3	19	-20
9	7	-9	5	22	22	5	19	-19	2	6	6	8	31	34	1	13	-14	4	4	-6
H,L=	0	3	6	28	-30	6	14	-16	3	16	-16	H,L=	2	4	2	10	-10	5	12	-12
0	43	-42	7	9	-10	H,L=	-7	4	4	34	-36	0	7	-7	3	11	12	6	40	43
1	16	-14	H,L=	5	3	0	28	-30	5	5	-2	1	12	11	H,L=	8	4	7	5	-6
2	43	-43	0	14	-14	1	15	16	6	33	-35	2	49	-50	1	15	16	H,L=	-4	5

K	FO	FC
0	22	22
1	9	10
2	48	-49
3	4	-5
4	35	-36
5	14	-14
6	15	16
7	14	-15
8	30	33
H,L=	-3	5
0	50	51
2	10	10
3	19	20
4	29	-30
5	15	16
6	20	-22
7	7	-7
8	12	13
H,L=	-2	5
0	19	19
1	8	-8
2	21	22
3	13	14
4	9	-10
6	20	-22

K	FO	FC
7	23	24
8	7	-7
H,L=	-1	5
0	3	1
1	9	8
2	21	21
3	20	-20
4	19	19
6	18	-20
7	7	-8
8	15	-16
H,L=	0	5
0	29	-31
1	11	-9
2	4	-2
3	11	11
4	8	9
6	16	18
7	4	-5
H,L=	1	5
0	12	11
2	19	-20
3	10	-11
4	18	19
6	19	20

K	FO	FC
H,L=	2	5
0	5	-5
2	5	-4
5	6	7
6	18	19
7	10	10
H,L=	3	5
0	12	-12
2	25	-25
3	6	-6
4	24	-25
5	11	-11
6	7	6
H,L=	4	5
0	25	28
1	10	11
2	11	-10
3	[illegible]	-3
4	40	-42
5	15	-16
6	14	-16
H,L=	5	5
0	36	38
2	6	5
3	15	17

K	FO	FC
4	9	-10
5	8	8
H,L=	6	5
0	18	20
1	11	-11
2	53	56
3	5	5
4	8	8
H,L=	7	5
2	26	28
H,L=	8	5
0	41	-44
H,L=	-8	6
0	10	11
1	5	4
3	19	-20
H,L=	-7	6
1	7	-7
2	24	25
3	7	-7
5	26	-29
H,L=	-6	6
1	17	18
2	9	9
4	26	27

K	FO	FC
5	5	4
6	5	-5
H,L=	-5	6
0	30	-33
1	5	-4
3	20	21
4	9	10
5	8	9
6	31	34
7	12	14
H,L=	-4	6
0	8	-9
2	41	-43
3	9	-10
4	29	31
5	16	18
6	11	11
7	10	11
H,L=	-3	6
0	45	-48
1	13	-15
2	31	-33
3	9	-10
4	41	-44
5	9	-9

K	FO	FC
6	28	30
H,L=	-2	6
0	63	67
1	8	8
2	41	-43
3	9	-10
4	39	-41
5	39	-40
6	17	-18
7	9	-11
H,L=	-1	6
0	57	60
1	29	30
2	37	39
4	37	-40
5	19	21
6	29	-31
7	28	-30
H,L=	0	6
0	44	46
1	25	-26
2	50	52
3	36	38
4	19	21
6	30	-32

K	FO	FC
7	16	16
H,L=	1	6
0	32	-32
1	11	12
2	50	54
3	11	-12
4	35	37
5	17	18
6	5	4
H,L=	2	6
0	59	-63
1	16	-17
2	31	-33
3	4	-4
4	22	23
5	10	-10
6	28	29
H,L=	3	6
0	15	-16
1	8	9
2	45	-48
3	24	-26
4	9	-9
5	7	-8
H,L=	4	6

K	FO	FC
0	21	23
1	7	-8
3	23	25
4	36	-38
5	11	-12
H,L=	5	6
0	48	52
1	18	19
2	11	12
3	7	-7
H,L=	6	6
1	5	-4
2	43	48
H,L=	7	6
0	13	-13
H,L=	-7	7
0	42	45
1	9	10
2	12	13
3	13	15
4	21	-23
H,L=	-6	7
0	28	29
2	26	27
3	4	2

K	FO	FC
4	13	14
5	26	29
H,L=	-5	7
0	13	-14
1	16	-18
2	33	36
3	6	-6
4	25	27
5	16	-16
H,L=	-4	7
0	37	-40
1	11	12
2	21	-21
3	18	-20
4	19	20
5	11	-11
6	18	20
H,L=	-3	7
0	23	-24
1	6	6
2	33	-36
4	25	-26
5	11	-13
6	20	22
H,L=	-2	7

K	FO	FC
0	31	33
2	22	-23
3	27	28
4	21	-22
5	5	5
6	18	-19
H,L=	-1	7
0	25	26
2	14	14
4	24	-25
5	19	21
6	16	-18
H,L=	0	7
0	32	34
1	11	-11
2	30	32
3	11	-12
5	8	-8
6	21	-22
H,L=	1	7
0	4	-3
2	25	26
3	6	-5
4	8	8
5	4	-3

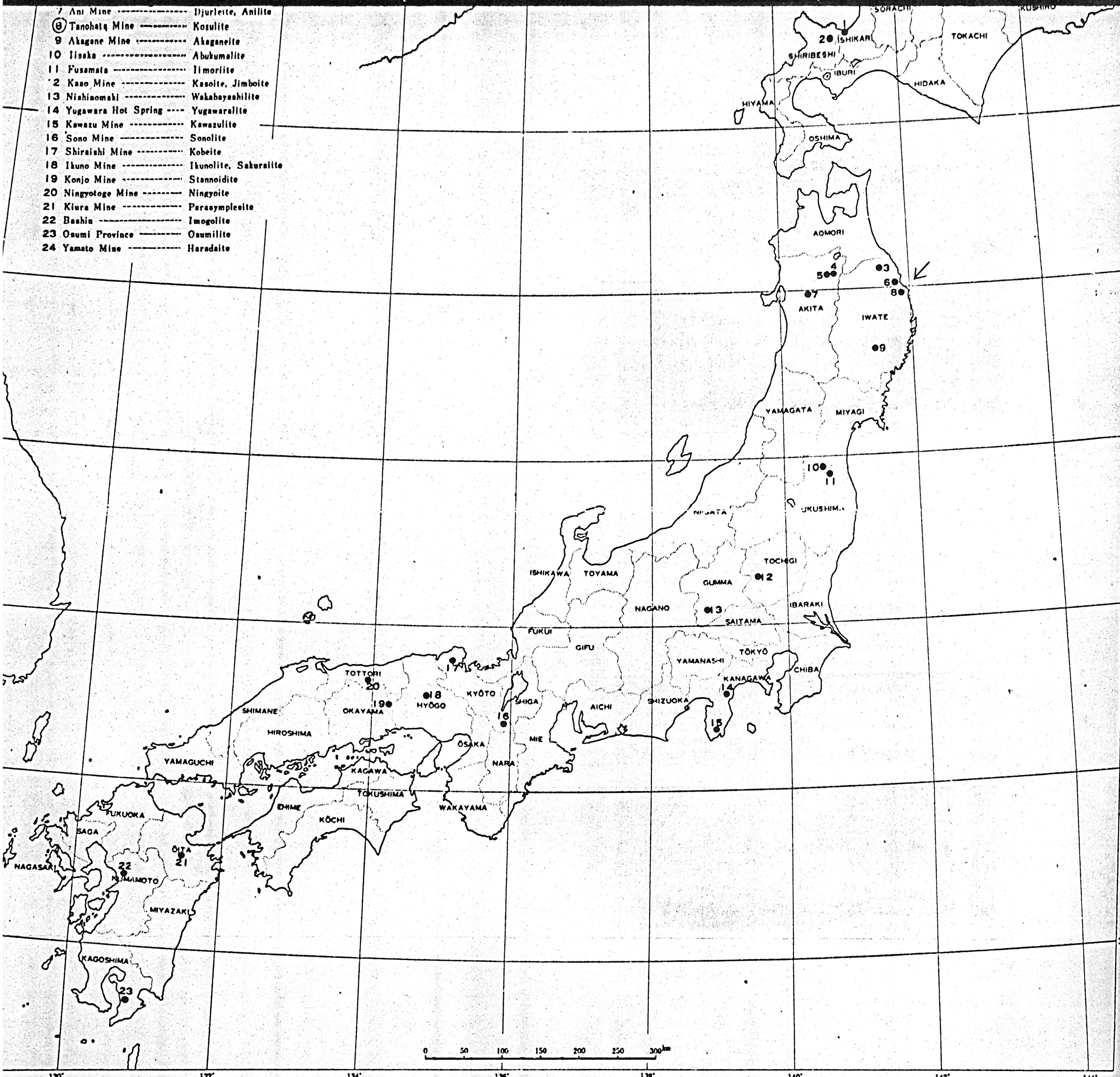
K	FO	FC
H,L=	2	7
2	9	9
4	23	24
5	5	-4
H,L=	3	7
0	29	-30
2	15	15
3	6	8
4	18	19
H,L=	4	7
0	31	-33
1	6	-8
2	18	-20
3	5	5
4	6	6
H,L=	5	7
0	5	-6
1	8	9
2	27	-29
H,L=	6	7
0	8	10
H,L=	-6	8
2	20	23
3	10	-11
H,L=	-5	8

K	FO	FC
0	19	21
2	10	9
3	19	20
4	8	8
H,L=	-4	8
1	18	20
2	20	20
4	13	14
H,L=	-3	8
1	21	-23
2	14	14
3	10	10
4	28	30
H,L=	-2	8
0	32	-35
1	3	1
2	16	-16
3	18	-20
4	8	9
H,L=	-1	8
0	13	-14
2	23	-24
3	8	-8
4	28	-30
5	30	-32

K	FO	FC
H,L=	0	8
0	27	29
1	19	20
2	17	-18
3	4	4
4	18	-19
H,L=	1	8
0	18	19
1	12	-11
2	35	37
3	30	31
4	14	-14
H,L=	2	8
0	23	24
2	31	33
H,L=	3	8
0	46	-51
1	8	-8
2	13	15
3	18	-19
H,L=	4	8
0	24	-26
1	11	-11
2	36	-39
H,L=	5	8

K	FO	FC
0	19	-20
H,L=	-3	9
0	34	-36
1	7	-8
2	7	8
H,L=	-2	9
0	38	-41
2	26	-28
3	8	-9
H,L=	-1	9
2	24	-25
3	8	9
H,L=	0	9
0	12	11
1	5	7
2	9	-10
H,L=	1	9
0	18	20
1	9	-9
2	11	12
H,L=	2	9
1	8	9
0	5	4


1 Teine Mine ---------- Teineite
2 Todoroki Mi e ---------- Todorokite
3 Kohare Mine ---------- Manjiroite
4 Hanawa Mine ---------- Fukuchilite
5 Osarizawa Mine ---------- Osarizawaite
6 Nodatamagawa Mine ---- Yoshimuraite
7 Ani Mine ---------- Djurleite, Anilite
8 Tanohata Mine ---------- Kozulite
9 Akagane Mine ---------- Akaganeite
10 Iisaka ---------- Abukumalite
11 Fusamata ---------- Iimoriite
12 Kaso Mine ---------- Kasoite, Jimboite
13 Nishinomaki ---------- Wakabayashilite
14 Yugawara Hot Spring ---- Yugawaralite
15 Kawazu Mine ---------- Kawazulite
16 Sono Mine ---------- Sonolite
17 Shiraishi Mine ---------- Kobeite
18 Ikuno Mine ---------- Ikunolite, Sakuraiite
19 Konjo Mine ---------- Stannoidite
20 Ningyotoge Mine ---------- Ningyoite
21 Kiura Mine ---------- Parasympleslite
22 Bashin ---------- Imogolite
23 Osumi Province ---------- Osumilite
24 Yamato Mine ---------- Haradaite
SŌYA
RUMOE
ABASHIRI
KAMIKAWA
NEMURO
SORACHI
KUSHIRO
TOKACHI
ISHIKARI
SHIRIBESHI
IBURI
HIDAKA
HIYAMA
OSHIMA
AOMORI
AKITA
IWATE
YAMAGATA
MIYAGI
FUKUSHIMA
NIIGATA
TOCHIGI
ISHIKAWA
TOYAMA
GUMMA
NAGANO
IBARAKI
SAITAMA
FUKUI
GIFU
TŌKYŌ
YAMANASHI
CHIBA
KANAGAWA
TOTTORI
KYŌTO
HYŌGO
OKAYAMA
SHIMANE
SHIGA
AICHI
SHIZUOKA
HIROSHIMA
MIE
ŌSAKA
YAMAGUCHI
KAGAWA
NARA
TOKUSHIMA
EHIME
WAKAYAMA
FUKUOKA
KŌCHI
SAGA
ŌITA
NAGASAKI
KUMAMOTO
MIYAZAKI
KAGOSHIMA
0 50 100 150 200 250 300km
130° 132° 134° 136° 138° 140° 142° 144° 146°



2. New minerals