Original paper

WinSpingc, a Windows program for spinel supergroup minerals

Fuat YAVUZ[1]*, Vural YAVUZ[2]

[1] *Department of Geological Engineering, Istanbul Technical University, 34469 Maslak, Istanbul, Turkey; yavuz@itu.edu.tr*
[2] *Department of Civil Engineering, Turkish-German University, 34820 Beykoz, Istanbul, Turkey; vural.yavuz@tau.edu.tr*
** Corresponding author*

A Microsoft® Visual Basic software, called WinSpingc, has been developed to calculate and classify wet chemical and electron-microprobe spinel supergroup mineral analyses based on the New Minerals, Nomenclature and Classification (CNMMN) of the International Mineralogical Association (IMA–19) nomenclature scheme. The program evaluates the 60 approved species according to the dominant valance and constituents in the general AB_2X_4 formula for the spinel, ulvöspinel, carrollite, linnaeite, tyrellite and bornhardtite subgroups that belong to the oxyspinel, thiospinel and selenospinel groups. Mineral analyses of the oxyspinel group are calculated based on 3 cations and 4 oxygen atoms per formula unit, whereas the formulae of thiospinel and selenospinel analyses are on the basis of 7 atoms per formula unit. Employing the anions of spinel supergroup mineral analyses, the program first assigns three groups on the basis of dominant X anion, including O^{2-}, S^{2-} and Se^{2-}, determines subgroups according to the cation charge arrangement combinations and then defines the spinel species in each subgroup based on the dominant valance and constituents. The Fe^{3+} and Fe^{2+}, as well as the Mn^{3+}, Mn^{2+}, Co^{3+} and Co^{2+} contents from microprobe-derived total FeO, MnO and CoO (wt. %) amounts, are estimated by stoichiometric constraints. WinSpingc allows the users to enter total 57 input variables for groups as well as to type and load the multiple spinel supergroup compositions in the data entry section, to edit and load the Microsoft® Excel files in calculating, classifying and naming the spinel species, and to store all the calculated parameters in the Microsoft® Excel file for further evaluations. The program is distributed as a self-extracting setup file, including the necessary support files used by the program, a help file, and representative sample data files.

Keywords: spinel, oxyspinel, thiospinel, selenospinel, classification, software
Received: 9 August 2022; accepted: 6 February 2023; handling editor: P. Bačík
The online version of this article (doi: 10.3190/jgeosci.369) contains supplementary electronic material.

1. Introduction

Spinel was one of the first minerals whose structure has been investigated in detail due to its simple structure type that provides incorporation of various monovalent to hexavalent cations, at least 36, within its structure (Bosi 2019). Despite their apparent simplicity, the spinel-type structure presents significant flexibility in cation and anion substitutions due to the interplay between tetrahedral and octahedral sites, which results in approximately five dozen minerals in mainly three oxyspinel, thiospinel and selenospinel groups. Thus, cations partitioning as a function of *P–T* conditions, the thermal expansion and the compressibility of the spinel structure are not only the interest for modelling the Earth's mantle, but also subject to a variety of geochemical and petrological applications, including geothermometers, geobarometers and geospeedometers (Biagioni and Pasero 2014; Yavuz and Döner 2017; Yavuz and Yıldırım 2018a; Yavuz 2013, 2021; Yavuz and Yavuz 2022). Besides some spinel species being the source of ore minerals (e.g., chromite for Cr and magnetite for Fe), the others can be used as gemstones (e.g., different colors of spinel species). Minerals with the natural spinel structure are observed in a wide range of geological (i.e., from the upper mantle to the crust) and extraterrestrial geological environments (e.g., the Moon, Mars, meteorites). On the other hand, materials with the spinel-type structure show different specifications regarding mechanical, optic, thermoelectric and magnetic properties. Hence, natural and synthetic materials with spinel-type structure are suitable for many applications in chemistry and materials science (Bosi 2019).

Most naturally encountered spinel species are oxides (e.g., chromite, magnetite and spinel) when compared to the other more rarely observed sulfides (e.g., carrollite, malanite and grimmite) and selenide (e.g., tyrrellite, bornhardite and trüstedtite) spinel-type minerals. If synthetic compounds in the spinel-type structure were considered, the spinel supergroup expands towards the halides, pseudohalides (cyanides), tellurides and nitrides. Consequently, spinel with X = O^{2-}, S^{2-} and Se^{2-} in the general formula AB_2X_4 occur in nature, whereas spinel with X = F^{1-}, Cl^{1-}, $(CN)^{1-}$, Te^{2-} and N^{3-} is produced as synthetic phase. Oxide spinels show a large compositional range with primary magmatic and/or secondary origin. The spinel structure consists of a cubic close-packed array of anions (e.g., O^{2-}, S^{2-}, Se^{2-}) with A (e.g., Cu, Mn, Mg) and B (e.g., Cr, Al, V) constituents occupying

Tab. 1 A list of the 60 IMA-approved species in the spinel supergroup (from Bosi et al. 2019a) classified by the WinSpingc program

	Oxyspinel group				
Row	*Spinel subgroup (2-3)*	Symbol	A^{2+}	B^{3+}	X
1	Chihmingite	Cim	Ni	Al_2	O_4
2	Chromite	Chr	Fe	Cr_2	O_4
3	Chukochenite	Ckc	$(Li^{+}_{0.5}Al^{3+}_{0.5})$	Al_2	O_4
4	Cochromite	Cchr	Co	Cr_2	O_4
5	Coulsonite	Cou	Fe	V_2	O_4
6	Cuprospinel	Cspl	Cu	Fe_2	O_4
7	Dellagiustaite	Dgt	V	Al_2	O_4
8	Deltalumite	Dal	$(Al_{0.67}\,\square_{0.33})$	Al_2	O_4
9	Franklinite	Frk	Zn	Fe_2	O_4
10	Gahnite	Ghn	Zn	Al_2	O_4
11	Galaxite	Glx	Mn	Al_2	O_4
12	Guite	Gui	Co	Co_2	O_4
13	Hausmannite	Hsm	Mn	Mn_2	O_4
14	Hercynite	Hc	Fe	Al_2	O_4
15	Hetaerolite	Hta	Zn	Mn_2	O_4
16	Jacobsite	Jcb	Mn	Fe_2	O_4
17	Maghemite	Mgh	$(Fe^{3+}_{0.67}\,\square_{0.33})$	Fe_2	O_4
18	Magnesiochromite	Mchr	Mg	Cr_2	O_4
19	Magnesiocoulsonite	Mcou	Mg	V_2	O_4
20	Magnesioferrite	Mfr	Mg	Fe_2	O_4
21	Magnetite	Mag	Fe	Fe_2	O_4
22	Manganochromite	Mnchr	Mn	Cr_2	O_4
23	Spinel	Spl	Mg	Al_2	O_4
24	Thermaerogenite	Tag	Cu	Al_2	O_4
25	Titanomaghemite	Tmgh	$(Ti^{4+}_{0.5}\,\square_{0.5})$	Fe_2	O_4
26	Trevorite	Trv	Ni	Fe_2	O_4
27	Vuorelainenite	Vuo	Mn	V_2	O_4
28	Zincochromite	Zchr	Zn	Cr_2	O_4
	Ulvöspinel subgroup (4-2)		A^{4+}	B^{2+}	X
29	Ahrensite	Ahr	Si	Fe_2	O_4
30	Brunogeierite	Bng	Ge	Fe_2	O_4
31	Filipstadite	Fps	$(Fe^{3+}_{0.5}Sb^{5+}_{0.5})$	Mn_2	O_4
32	Qandilite	Qnd	Ti	Mg_2	O_4
33	Ringwoodite	Rwd	Si	Mg_2	O_4
34	Tegengrenite	Teg	$(Mn^{3+}_{0.5}Sb^{5+}_{0.5})$	Mg_2	O_4
35	Ulvöspinel	Uspl	Ti	Fe_2	O_4
	Thiospinel group				
	Carrollite subgroup (1-3.5)		A^{1+}	$B^{3.5+}$	X
36	Carrollite	Cli	Cu	Co_2	S_4
37	Cuproiridsite	Cir	Cu	$(Ir^{3+}Ir^{4+})$	S_4
38	Cuprokalininite	Ckal	Cu	$(Cr^{3+}Cr^{4+})$	S_4
39	Fletcherite	Ftc	Cu	Ni_2	S_4
40	Florensovite	Frs	Cu	$(Cr^{3+}_{1.5}Sb^{5+}_{0.5})$	S_4
41	Malanite	Mla	Cu	$(Ir^{3+}Pt^{4+})$	S_4
42	Rhodostannite	Rhs	Cu	$(Fe^{2+}_{0.5}Sn^{4+}_{1.5})$	S_4
43	Toyohaite	To	Ag	$(Fe^{2+}_{0.5}Sn^{4+}_{1.5})$	S_4
	Linnaeite subgroup (2-3)		A^{2+}	B^{3+}	X
44	Cadmoindite	Cad	Cd	In_2	S_4
45	Cuprorhodsite	Crh	$(Cu^{+}_{0.5}Fe^{3+}_{0.5})$	Rh_2	S_4
46	Daubréelite	Dau	Fe	Cr_2	S_4
47	Greigite	Grg	Fe	Fe_2	S_4
48	Grimmite	Gmm	Ni	Co_2	S_4
49	Indite	Idt	Fe	In_2	S_4
50	Joegoldsteinite	Jgs	Mn	Cr_2	S_4
51	Kalininite	Kal	Zn	Cr_2	S_4
52	Linnaeite	Lin	Co	Co_2	S_4
53	Polydymite	Pld	Ni	Ni_2	S_4
54	Siegenite	Seg	Co	Ni_2	S_4
55	Violarite	Vio	Fe	Ni_2	S_4
56	Xingzhongite	Xin	Pb	Ir_2	S_4
	Selenospinel group				
	Tyrrellite subgroup (1-3.5)		A^{1+}	$B^{3.5+}$	X
57	Nickeltyrrellite	Nty	Cu	Ni_2	Se_4
58	Tyrrellite	Ty	Cu	$(Co,Ni)_2$	Se_4
	Bornhardtite subgroup (2-3)		A^{2+}	B^{3+}	X
59	Bornhardtite	Bhd	Co	Co_2	Se_4
60	Trüstedtite	Trü	Ni	Ni_2	Se_4

Symbols from Warr (2021). Chihmingite (Hwang et al. 2022), chukochenite (Rao et al. 2022), grimmite (Škácha et al. 2021) and nickeltyrrellite (Förster et al. 2019) are new spinel species approved by the IMA later than the subcommittee report by Bosi et al. (2019a).

one-eighth of the tetrahedrally (i.e., *T*) and one-half of the octahedrally (i.e., *M*) coordinated sites (Bosi 2019). Traditionally, spinels are represented by either "normal", where the *T* site is occupied by divalent (e.g., Fe^{2+}, Mn^{2+}, Ni^{2+}) cations and the *M* site by trivalent (e.g., Fe^{3+}, Mn^{3+}, Ni^{3+}) cations or "inverse", where the *T* site is occupied by trivalent cations and the *M* site by one divalent plus one trivalent cation (Bosi et al. 2019a).

Although various computer programs for the calculation and classification of rock-forming silicate minerals have been published over the past two decades (e.g., Yavuz, 2001, 2003, 2007; Yavuz et al. 2014, 2015; Yavuz and Yıldırım 2018b, 2020), software on the classification of spinel supergroup minerals, according to the current IMA report (Bosi et al. 2019a), has not yet been appeared in literature, except for programs specially focused on chromian spinels (Yavuz 1999; Ganuza et al. 2012, 2014; Antonini et al. 2020). In this paper, a computer program, WinSpingc, has been developed using the Microsoft® Visual Basic programming language to calculate multiple spinel supergroup mineral data, up to 200 analyses at a time, obtained from wet chemical and electron-microprobe techniques. The program estimates and classifies oxyspinel group mineral analyses on the basis of 3 cations and 4 oxygen atoms per formula unit "*apfu*". On the other hand, the formulae of thiospinel and selenospinel analyses were calculated based on "7 *apfu*". Calculation and classification of spinel supergroup mineral analyses are carried out based on the current IMA report (Bosi et al. 2019a). The program is capable of estimating the FeO, Fe_2O_3,

MnO, Mn_2O_3, CoO and Co_2O_3 (wt. %) contents from a microprobe-derived total FeO, MnO and CoO (wt. %) analysis using the stoichiometric constraints proposed by Droop (1987). WinSpingc allows the user to display spinel supergroup minerals in several binary and ternary classification and variation diagrams by using the Golden Software's Grapher program. When compared to the published previous spinel-related computer programs, WinSpingc provides users with a quick evaluation of multiple spinel analyses for calculation and classification purposes according to the current IMA-approved nomenclature scheme by Bosi et al. (2019a).

2. Spinel supergroup minerals nomenclature

Considering that mineral nomenclature aims at identifying and naming minerals as well as mineral classification aims at grouping minerals based on their similar properties and reciprocal relations, Bosi et al. (2019b) defined the meaning of mineral formulae and suggested a coherent procedure to identify mineral species based on their formula with contradictions in the current mineral classification scheme. In this respect, the 60 valid minerals of the spinel supergroup have been divided into three groups (i.e., oxyspinel, thiospinel and selenospinel) by Bosi et al. (2019a, see Tab. 1) based on the dominant X species (i.e., anions) in the general AB_2X_4 formula. In each group, the subdivision procedure into subgroups is carried out according to the cation charge arrangement combinations considering the (A+B) to X atomic ratio of 3:4 (Bosi et al. 2019a). Using this criterion, for example, the oxyspinel group, consisting of 34 species, is divided into the spinel subgroup (2-3) and ulvöspinel subgroup (4-2), where the numbers in parentheses show the charges of cations in A and B (see Tab. 1). According to Bosi et al. (2019a), the subdivision scheme can easily be extended such as subgroups (2-1) and (6-1) if the natural AB_2X_4 compound with spinel structure is discovered as a new mineral species.

In the spinel classification procedure by a chemical formula, cations at the sites are grouped together and then each species is determined systematically by stoichiometry based on the chemical formula. Bosi et al. (2019a) pointed out that the total variations in spinel composition can easily be described in the ternary system A–B–X, where A and B parameters indicate the greatest degree of variation in terms of cations. However, the system may be reduced to binary A–B if the anion X is specified. As the electroneutrality principle constrains the variation of A and B parameters, only one parameter, the most abundant constituent B in the general formula, is considered to determine the subgroup (Bosi et al. 2019a). Thus, using the recalculated chemical analytical data and considering the dominant-valency rule, the dominant valence can be determined for the B parameter by summing the ions for each valence. For example, total divalent ($\sum R^{2+} = Mg^{2+} + Fe^{2+} + Mn^{2+} + Cu^{2+} + Zn^{2+} + Co^{2+} + Ni^{2+} + V^{2+}$) and trivalent ($\sum R^{3+} = Cr^{3+} + Fe^{3+} + Al^{3+} + Mn^{3+} + Co^{3+}$) cations are used to determine the subgroups (2-3) and (4-2) of oxyspinels, which are characterized by $\sum R^{3+} > 1.0$ "*apfu*" and $\sum R^{2+} > 1.5$ "*apfu*", respectively. Bosi et al. (2019a) also stated that the ratio $\sum R^{3+}/\sum R^{2+}$ can be used to distinguish between the oxyspinels of subgroups (2-3) and (4-2) that can be varying from 0.67 to 2 and 0 to 0.67 values, respectively. Finally, once the valence of B is established, the dominant B-cation and then the dominant A-cation are identified, considering the dominant-constituent rule in which heterovalent pairs of ions also should be taken into account for a proper classification purpose.

Thiospinels and selenospinels (i.e., chalcospinels) are isostructural with oxyspinels, with the anions specified by S^{2-} and Se^{2-} in the structure, respectively. Although some uncertainties in the ion oxidation states may cause difficulties in the classification of the thiospinel and selenospinel groups and species, they can be divided into the carrollite (1-3.5), linnaeite (2-3), tyrrellite (1-3.5) and bornhardtite (2-3) subgroups (see Tab. 1). Despite chalcospinels have fewer species (i.e., 25) than oxyspinels (i.e., 34), a large number of synthetic spinel structure compounds with S^{2-} and Se^{2-} have been reported in the literature (Biagioni and Pasero 2014). Albeit the classification of Cu-bearing chalcospinels is more problematic, many of them, including considerable amounts of Cr, Mn, Fe, Co, Ni, Zn, Cd, and In in structure, could be reasonably assigned to subgroup (2-3). According to Bosi et al. (2019a), the charge of ions, for example, in carrollite, fletcherite and tyrrellite, is a matter of discussion. Hence, it is assumed that the oxidation states of anions (i.e., S and Se) and Cu are –2 and +1, respectively. Note that Co^{4+} is a result of the S^{2-} assumption. Spinels with Co^{4+} have not yet been found in nature due to unlikely redox conditions in crustal environments. Thus, the occurrence of cobalt and nickel in Co^{3+}, Co^{4+}, Ni^{3+} and Ni^{4+} oxidation states leads to $B^{3.5+}$. Consequently, carrollite, fletcherite and tyrrellite in chalcospinels fall into subgroups (1-3.5).

3. Program description

WinSpingc is a user-friendly compiled program package (20 Mb) for spinel supergroup mineral analyses developed for personal computers on the Microsoft® Windows operating system. The program first calculates cations "*apfu*" from electron-microprobe and wet chemical spinel supergroup analyses. Then it classifies the valid 60 species that belong to three groups, including the oxyspinel, thiospinel and selenospinel, within six subgroups

a

WinSpingc

File Edit Calculate About Help

WinSpingc, A Windows Program for Spinel Supergroup Minerals — Data Entry Screen

Row No	Sample No [Oxyspinel]	SiO2	TiO2	GeO2	Al2O3	Ti2O3	Cr2O3	V2O3	Fe2O3	Mn2O3	Co2O3	VO	FeO	MgO	CaO	MnO	CuO	ZnO	CoO	NiO	Na2O	K2O	Li2O	Sb2O5
1	Chromite		0.26		9.89		52.17	0.28	5.88				25.48	5.28										
2	Cochromite	0.11	1.26		9.11		50.38		4.14				7.45	0.95		0.84		0.59	17.45	7.67				
3	Coulsonite	0.01	0.22		1.02		24.99	39.98					27.21			2.31		3.79						
4	Cuprospinel				2.6				65.7				1.7	1.8		0.2	27.8	0.7	0.6					
5	Dellagiustaite	0.02	0.73		32.63	0.66		34.88				23.5		7.23		0.41								
6	Deltalumite	0.04			99.74																			
7	Franklinite		0.7		1.25				63.9				3.6			0.6		30.25						
8	Gahnite	0.03			57.71								7.85	0.61		0.65		34.06						
9	Galaxite		0.05		56.3			0.14	4.6					0.83		39.1		0.43	0.25					
10	Gute	0.54														0.87	0.73		90.95					
11	Hausmannite												0.01			91.38								
12	Hercynite				60.7								34.7	4.3		0.2								
13	Hetaerolite	0.18							0.24	64.21				0.49		1.86		32.46						
14	Jacobsite		0.38		8.14				59.5				0.5	0.03		32.1								
15	Maghemite	0.3	13		1.8				74.6					8.4		0.9								
16	Magnesiochromite		0.03		17.64		52.33		1.12				16.1	12.13										
17	Magnesiocoulsonite		0.14		0.36		28.09	50.07					0.2	20.90		0.18								
18	Magnesioferrite	0.06			1.63		10.08		67.05				3.15	17.25	0.1	1.01				1.06				
19	Magnetite	0.11	0.29		0.44		0.08		67.16				31.21	0.02		0.09								
20	Manganochromite		0.2				35.9	30.5					5.3			26.3		0.7						
21	Spinel	0.02	0.05		70.08								0.33	28.77				0.33						
22	Thermaerogenite				39.43		0.27		17.96								25.01	17.45						
23	Titanomaghemite	0.68	22.17		1.9				73.26							1.46								
24	Trevorite	1.4							66.24				1.96	0.24						29.71				
25	Vuorelainenite		0.1				19.5	47.4					5.7	0.1		26.4		0.8						
26	Zincochromite	2.82	0.14		1.14		53.3	3.52	2.03									37.05						
27	Chukochenite	0.04	0.02		80.7		0.01		8.16					1.7	0.08	2.49		3.25			0.11	0.01	3.68	

b

WinSpingc

File Edit Calculate About Help

WinSpingc, A Windows Program for Spinel Supergroup Minerals — Data Entry Screen

Row No	Sample No [Thiospinel]	Cu	Ag	Cd	Fe	Mn	Zn	Ge	Co	Ni	Pb	Bi	Cr	V	In	Sb	As	Sn	Ir	Pd	Pt	Rh	Se	Te	S
1	Carrollite	20.2			0.6				38.6	0.3															41.2
2	Cuproiridsite	7.41			3.17					0.27									48.9		10.5	6.05			24.6
3	Cuprokalininite	21.03			0.47		0.17						29.01	5.85		0.08	0.21								43.25
4	Fletcherite	19.5			0.9				13.6	25.9															41.6
5	Florensovite	18.8					0.75						24.24	0.02		19.17									38.45
6	Malanite	9.95			1				2.6	0.33									25.23	0.45	36.77				23.47
7	Rhodostannite	16			6.8													45.5							31.3
8	Toyohaite	0.14	24.39	0.22	6.28		0.37								0.05			41.24							28.16
9	Cadmoindite			19.98	1.71		0.77	0.29							49.51										27.53
10	Cuprorhodsite	7.55			5.31														10.3		6.8	39.6			29.8
11	Daubreelite				20.1								35.91												42.69
12	Greigite	0.08			56.5		0.01			0.1			0.14				0.38								42.2
13	Indite				8.84										59.3										31.85
14	Joegoldsteinite	0.08			4.5	15.8				0.09			36.2												44.3
15	Kalininite	2.73					18.89						34.10	0.61		0.73									42.22
16	Linnaeite	8.79			1.30				40.71	7.35															41.43
17	Polydymite				3.98				0.63	54.3															41.09
18	Grimmite	0.08			1.16	0.03			38.23	19.27	0.46	0.62					0.09								41.05
19	Siegenite	3.16			3.22				20.36	31.24															42.43
20	Violarite	1.12			17.01				1.05	38.68															41.68
21	Xingzhongite	3.81			1.58						12.8								43.49		9.67	7.19			21.68
27																									

c

WinSpingc

File Edit Calculate About Help

WinSpingc, A Windows Program for Spinel Supergroup Minerals — Data Entry Screen

Row No	Sample No [Selenospinel]	Cu	Fe	Co	Ni	Pb	S	Se
1	Tyrrellite	12.7		17.7	6.9			62.4
2	Nickeltyrrellite	13.01	0.27	6.66	16.98		1.04	61.91
3	Trüstedtite			6.4	29.5			64.4
27								

C:\Program Files (x86)\WinSpingc\Species.ssg 10:24 AM 7/5/2022 by

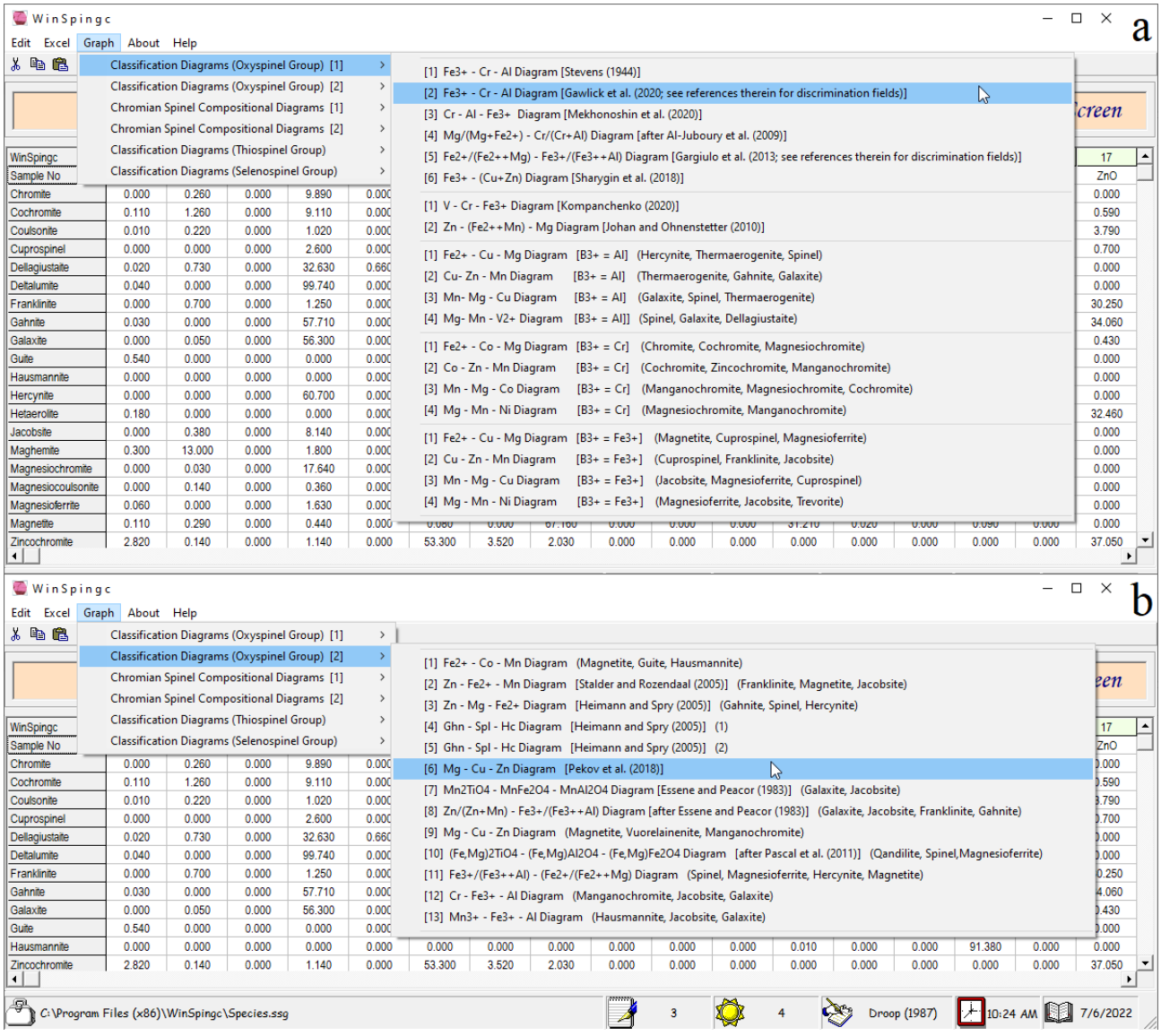

Fig. 2a, b – Screenshots of the binary and ternary classification diagram types for oxyspinels from the pull-down menu of *Graph* in the *Calculation Screen*.

consisting of the spinel (2-3), ulvöspinel (4-2), carrollite (1-3.5), linnaeite (2-3), tyrrellite (1-3.5) and bornhardtite (2-3) (see Tab. 1). A list of the calculation steps in the *Calculation Screen* and an Excel output of the developed program is given in Tab. 2. Current version of WinSpingc presents total 76 binary and ternary classification as well as chromian spinel (Cr-spinel) compositional plots. The Golden Software's Grapher program displays these plots by selecting any diagram type from the pull-down menu of *Graph* in the *Calculation Screen* of WinSpingc.

⇦

Fig. 1 – Screenshots of the WinSpingc *Data Entry Screen* window showing data edit of spinel supergroup minerals. **a** – The standard 23 variables (wt. %) for oxyspinel (wt. %) mineral analyses. **b** – The standard 24 variables for thiospinel (%) mineral analyses. **c** – The standard seven variables for selenospinel (%) mineral analyses.

3.1. Data entry of spinel supergroup analyses

Upon successful installation of WinSpingc, the start-up screen with various pull-down menus and equivalent shortcuts appears on the screen. The program allows the user to type wet chemical or electron-microprobe oxyspinel (Fig. 1a), thiospinel (Fig. 1b) and selenospinel (Fig. 1c) analyses both together or as a separate form by clicking the *New* icon on the toolbar, by selecting the *New File* from the pull-down menu of *File* option or pressing the *Ctrl+N* keys. In the *New File*, *Data Entry Screen,* and *Calculation Screen*, these parameters are highlighted by the soft green, pink and blue colors, respectively. WinSpingc uses the standard 57 variables (wt. %) for the calculation and classification of spinel supergroup mineral analyses as in the following orders:

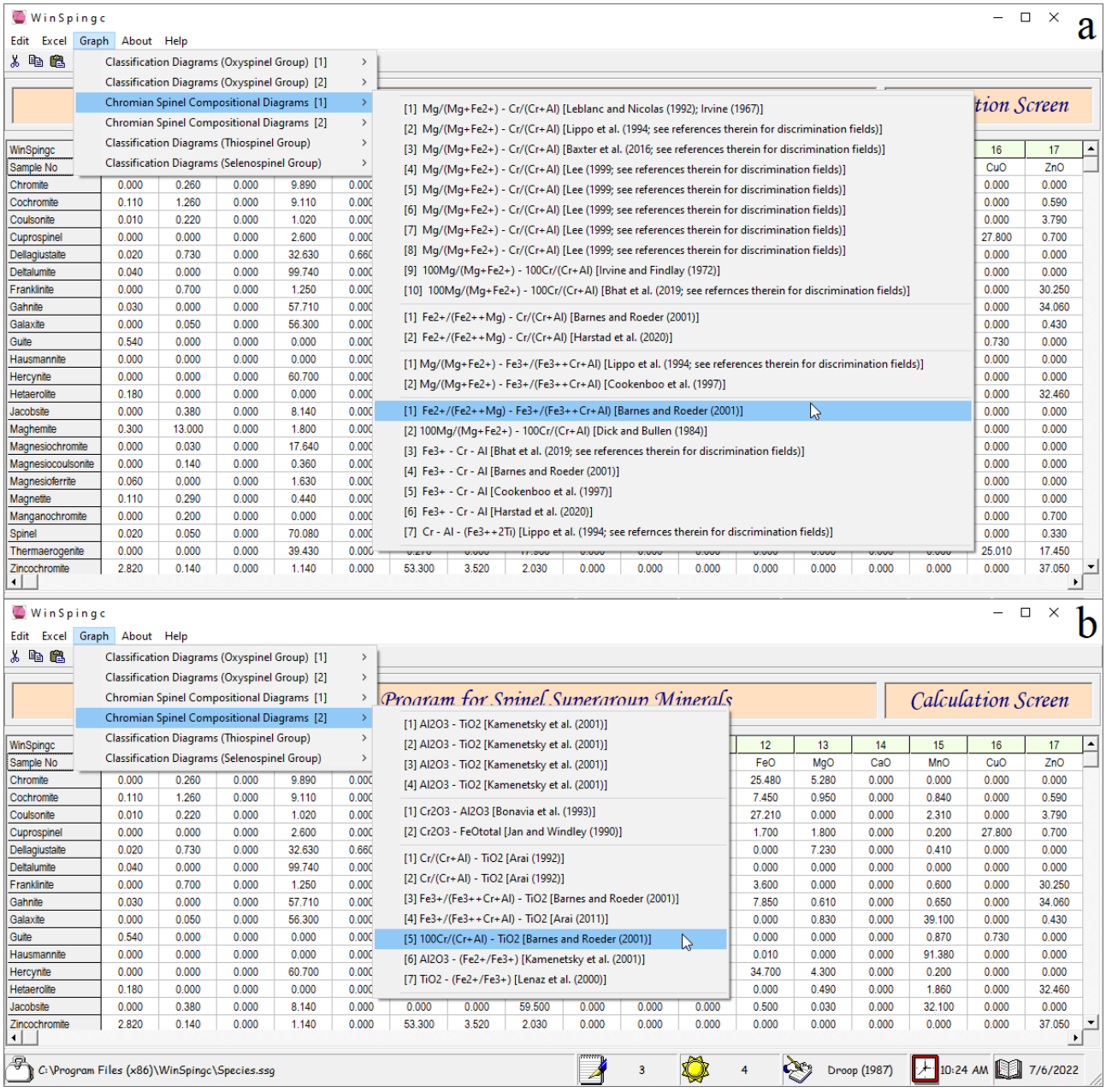

Fig. 3a, b – Screenshots of the binary and ternary chromian spinel (Cr-spinel) diagram types from the pull-down menu of *Graph* in the *Calculation Screen*.

Sample No [Oxyspinel], SiO_2, TiO_2, GeO_2, Al_2O_3, Ti_2O_3, Cr_2O_3, V_2O_3, Fe_2O_3, Mn_2O_3, Co_2O_3, VO, FeO, MgO, CaO, MnO, CuO, ZnO, NiO, Na_2O, K_2O, Li_2O and Sb_2O_5 (wt. %).

Sample No [Thiospinel], Cu, Ag, Cd, Fe, Mn, Zn, Ge, Co, Ni, Pb, Bi, Cr, V, In, Sb, As, Sn, Ir, Pd, Pt, Rh, Se, Te, Se (wt. %).

Sample No [Selenospinel], Cu, Fe, Co, Ni, Pb, S, Se (wt. %).

Spinel supergroup analyses typed in an Excel file with the extension of ".xls" and ".xlsx" as in the above order can be loaded into the program's *Data Entry Screen* by clicking the *Open Excel File* option from the pull-down menu of *File*. By selecting the *Edit Excel File* option from the pull-down menu of *File*, these can be typed in a blank Excel file (i.e., MySpinel), stored in a different file name with the extension of ".xls" or ".xlsx", and then loaded into the program's *Data Entry Screen* by clicking the *Open Excel File* option from the pull-down menu of *File*. Additional information about data entry or similar topics can be accessed by pressing the F1 function key to display the WinSpingc.chm file on the screen.

3.2. Chromian spinel compositional plots

Chromian spinel (Cr-spinel) minerals are important petrogenetic and geochemical indicators crystallizing over a wide range of *P-T* conditions in igneous and metamorphic rocks within different geological environments (e.g., Irvine 1965; Dick and Bullen 1984; Barnes and Roeder 2001). Cr-spinel composition has an important role in understanding the upper mantle processes associated with mantle melting and parental melt interactions (Arai et al. 2006). Since the chemical compositions of Cr-spinels were affected by geological factors, including magma composition, sequence of crystallization, oxygen fugacity as well as the *P-T* conditions, they also provide Earth scientists with the determination of the different tectonic setting regimes (Dick and Bullen 1984; Sack and Ghiorso 1991; Arai 1992; Barnes and Roeder 2001; Kamenetsky et al. 2001; Arai et al. 2011; Ghosh et al. 2013). Chromite, as a pure end-member of Cr-spinel, in mafic and ultramafic rocks has great economic importance due to the source of chromium ore (Ganuza et al. 2014). Although primary minerals, including olivine and pyroxene in ophiolitic rocks, were subjected to the extensive alteration processes that result in secondary low-temperature minerals such as serpentine and chlorite, the Cr-spinel may be preserved as the primary phase even in completely serpentinized peridotites (Arai 1994a; Bhat et al. 2019). Consequently, the composition of Cr-spinel from mafic and ultramafic rocks is considered in understanding the tectonic setting and petrogenetic processes of host rocks as well as the rate of mid-ocean ridge spreading in numerous earth science studies (e.g., Irvine 1965, 1967; Dick and Bullen 1984; Barnes and Roeder 2001; Kamenetsky et al. 2001; Arai 1992, 1994a, b; Gamal El Dien et al. 2019). However, during low-temperature alteration processes, the chemical composition of primary Cr-spinel may result in a secondary mineral form, called "ferritchromite", depending on the degree of alteration, but have chemical characteristics that are similar to the primary mantle Cr-spinel compositions (Arai 1978; Arai et al. 2006; Bhat et al. 2019). Cr-spinel, which is found as an accessory mineral in detrital rocks, preserves its compositional signature in buried sedimentary environments due to its mechanical stability; for that reason, it has been used not only in petrogenetic evaluations but also in provenance studies (Lenaz and Princivalle 2005; see references therein). However, Gamal El Dien et al. (2019) demonstrated that the composition of Cr-spinel can be modified by fluid/melt-rock interactions in both sub-arc and sub-mid oceanic mantle environments. Although the Cr# [i.e., Cr/(Cr+Al)] of Cr-spinels is an important geochemical parameter for the estimation of the degree of partial melting as well as the provenance of peridotites, metasomatism may cause Al-Cr heterogeneity in Cr-spinel composition which lowers the Cr/Al ratio, and therefore changes the Cr#, making Cr# ineffective as a geotectonic and mantle melting indicator (Voigt and von der Handt 2011; Gamal El Dien et al. 2019).

It is common to show spinel supergroup mineral analyses in binary and ternary diagrams for compositional and classification purposes. Some of these plots allow users to determine the spinel species using the cationic values. The current version of WinSpingc enables the users to use a total of 42 visual classification diagrams (e.g., Stevens 1944; Essene and Peacor 1983; Heimann and Spry 2005; Stalder and Rozendaal 2005; Al-Juboury et al. 2009; Johan and Ohnenstetter 2010; Pascal et al. 2011; Gargiulo et al. 2013; Pekov et al. 2018; Sharygin et al. 2018; Gawlick et al. 2020; Kompanchenko 2020; Mekhonoshin et al. 2020) for oxyspinel group compositional data using the Golden Software's Grapher program. These plots are displayed by selecting the desired diagram type from the pull-down menu of *Graph* in the *Calculation Screen* window of WinSpingc (Fig. 2a, b). Most Cr-spinel-related plots are based on the divalent and trivalent ions for mafic and ultramafic rocks in several geological environments and tectonic settings. The program provides the users total of 34 different plots (e.g., Irvine 1967; Irvine and Findlay 1972; Leblanc and Nicolas 1992; Lippo et al. 1994; Cookenboo et al. 1997; Lee 1999; Barnes and Roeder 2001; Baxter et al. 2016; Harstad et al. 2020) of compositional fields for Cr-spinels (Fig. 3a, b). On the other hand, WinSpingc visually classifies some of the spinel species that belong to the thiospinel and selenospinel groups by selecting the desired diagram type (e.g., Ostwald 1978; Barkov et al. 2000; Yajima et al. 1991; Förster et al. 2019) from the pull-down menu of *Graph* in the *Calculation Screen* window (Fig. 4a, b).

4. Worked examples

Using the selected data set from the literature, the following examples show how WinSpingc can be used to estimate and classify the spinel supergroup minerals. Once the previously typed or loaded spinel supergroup analyses are processed by clicking the *Calculate icon* (i.e. ∑) in the *Data Entry Section* of the program, all input and estimation parameters are displayed in columns 1-163 (see Tab. 2) of the *Calculation Screen* for oxyspinels, thiospinels and selenospinels highlighted by the soft green, pink and blue colors, respectively. Pressing the Ctrl+F keys or clicking the *Open File to Calculate* option from the *Calculate* menu also executes the data processing for a selected data file with the extension of ".ssg". By clicking the *Send results to Excel file* icon in the *Calculation Screen*, all calculations can be stored in

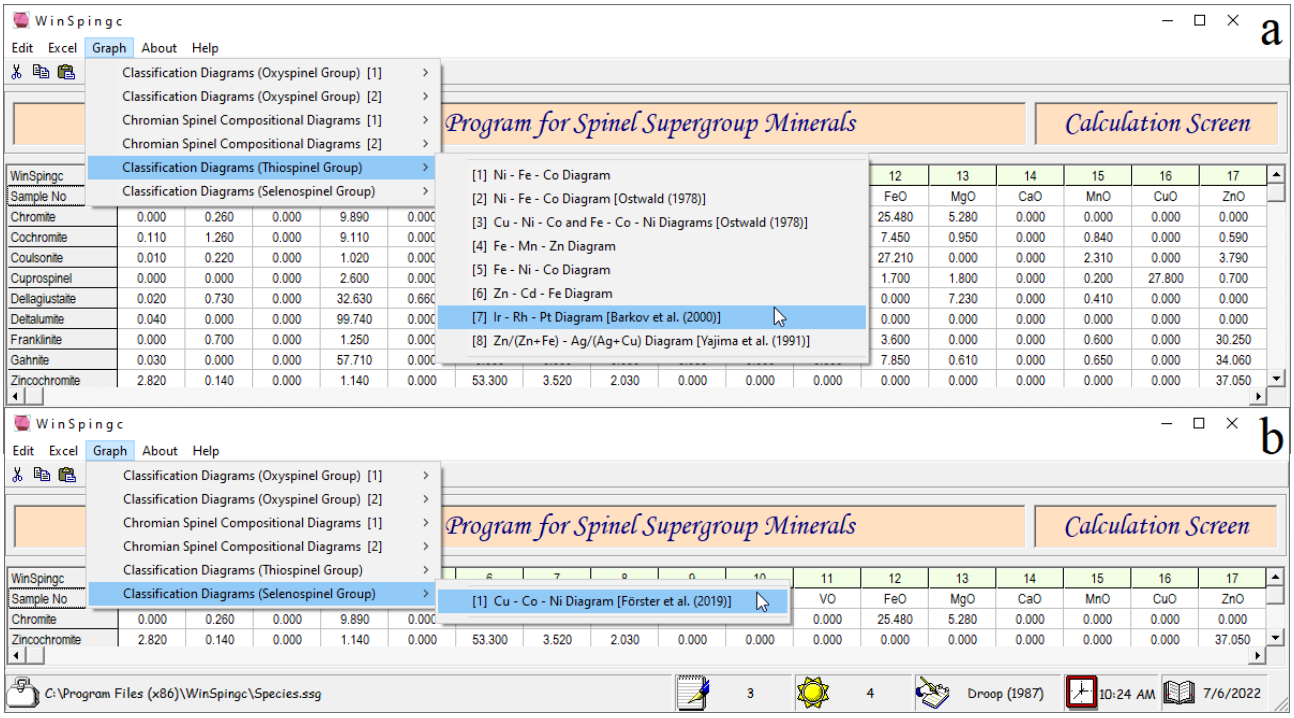

Fig. 4a, b – Screenshots of the binary and ternary classification diagram types for thiospinels and selenospinels from the pull-down menu of *Graph* in the *Calculation Screen*.

Tab. 2 Description of column numbers in the *Calculation Screen* window of WinSpingc program and an output Excel file

Row	Explanations	Column Numbers
1	Major oxide oxyspinel mineral analyses (wt.%)	1–24
2	Blank	25
3	Recalculated oxyspinel FeO, Fe_2O_3, MnO, Mn_2O_3, CoO and Co_2O_3 (wt.%) contents based on the stoichiometric constraints	26–31
4	Blank	32
5	Recalculated cations of oxyspinel mineral analyses "*apfu*"	33–56
6	Blank	57
7	Some useful cation ratio values [e.g., $Fe^{2+}/(Fe^{2+}+Mg)$, Cr/(Cr+Al)] for Cr–spinels	58–65
8	Blank	66
9	Total divalent to pentavalent cations (i.e., R^{2+}, R^{3+}, R^{4+}, R^{5+}) of oxyspinel mineral analyses "*apfu*"	67–70
10	Blank	71
11	Dominant A and B cations of oxyspinel mineral analyses	72–73
12	Blank	74
13	Group, subgroup and species of oxyspinel mineral analyses	75–77
14	Blank	78
15	Major oxide thiospinel mineral analyses (wt.%)	79–104
16	Blank	105
17	Recalculated cations and anions of thiospinel mineral analyses "*apfu*"	106–130
18	Blank	131
19	Dominant A and B cations of thiospinel mineral analyses	132–133
20	Blank	134
21	Group, subgroup and species of thiospinel mineral analyses	135–137
22	Blank	138
23	Major oxide selenospinel mineral analyses (wt.%)	139–147
24	Blank	148
25	Recalculated cations and anions of selenospinel mineral analyses "*apfu*"	149–156
26	Blank	157
27	Dominant A and B cations of selenospinel mineral analyses	158–159
28	Blank	160
29	Group, subgroup and species of selenospinel mineral analyses	161–163
30	Blank	164

"apfu" = Atoms per formula unit; R^{2+} = Total divalent cations, R^{3+} = Total trivalent cations, R^{4+} = Total tetravalent cations, R^{5+} = Total pentavalent cations

an Excel file (Output.xlsx) and then displayed by clicking the *Open and edit Excel file* icon.

The validity of program outputs has been tested with representative spinel supergroup mineral analyses (see Tab. 3, Tab. 4, and Tab. 5) selected from literature (e.g., Yajima et al. 1991; Anthony et al. 2001–2005; Cámara et al. 2019; Förster et al. 2019; Kompanchenko 2020; Škácha et al. 2021; Lei et al. 2022). WinSpingc calculates spinel supergroup mineral analyses based on 3 cations and 4 oxygens for oxyspinel group (see rows 31–54 in Tab. 3) and "7 *apfu*" for thiospinel and selenospinel groups (see rows 26–50 in Tab. 4 and rows 9–16 in Tab. 5), respectively.

The program provides the users with some of the useful ratios (see rows 55–62 in Tab. 3), such as Fe^{2+}/(Fe^{2+}+Mg) and Cr/(Cr+Al), especially for Cr-spinels, in the *Calculation Screen*. Total divalent and trivalent cations, as well as tetra- and pentavalent cations that are used in the classification of oxyspinel mineral analyses are listed (see rows 63–66 in Tab. 3) by the program in the *Calculation Screen*. Similarly, dominant A and B cations with spinel group, subgroup names, and species according to the nomenclature scheme by Bosi et al. (2019a) are also presented in the *Calculation Screen* window for selected spinel supergroup mineral analyses from literature (see rows 67–71 in Tab. 3, rows 51–55 in Tab. 4, rows 17–21 in Tab. 5).

WinSpingc provides various binary and ternary classification and Cr-spinel compositional diagrams in the *Calculation Screen* using Golden Software's Grapher program. Some of these plots with selected spinel supergroup mineral analyses from literature (e.g., Ostwald 1978; Essene and Peacor 1983; Oktyabrsky et al. 1992; Beard and Tracy 2002; Heimann and Spry 2005; Nekrasov et al. 2005; Beckett-Brown et al. 2018; Harstad et al. 2020) are given in an Electronic Supplementary Material (i.e., ESM 1).

5. Summary and availability of the program

WinSpingc is a user-friendly program specially developed for personal computers running on the Windows operating system to estimate and classify the spinel supergroup mineral analyses obtained from electron-microprobe and wet chemical analyses. The program calculates multiple spinel supergroup analyses, up to 200, for each program execution. Following the procedure by Droop (1987), WinSpingc estimates the Fe^{2+} and Fe^{3+} and, if necessary, Mn^{2+}, Mn^{3+}, Co^{2+} and Co^{3+} "*apfu*" contents from electron-microprobe oxyspinel analyses using the stoichiometric constraints. The program classifies the 60 valid spinel supergroup minerals into three groups, including oxyspinel, thiospinel and selenospinel based on the current IMA-approved nomenclature scheme proposed by Bosi et al. (2019a), taking into account the dominant X species in the general AB_2X_4 formula.

WinSpingc generates two main windows. The first window (i.e., *Start-up/Data Entry Screen*), with several pull-down menus and equivalent shortcuts, enables to edit spinel supergroup analyses (wt. %). By clicking the *Calculate* icon (i.e. ∑) in the *Data Entry Screen*, all input and estimated parameters by WinSpingc are displayed in the second window (i.e., *Calculation Screen*). The program reports the output in a tabulated form with a numbered column from 1 to 163 in the *Calculation Screen* window. Calculated oxyspinel, thiospinel and selenospinel parameters, together with the classification subgroups and mineral species, are displayed in 1–77, 80–137, and 140–163 column numbers in the *Calculation Screen*, respectively as well as in an Output Excel file. The results in the *Calculation Screen* can be exported to a Microsoft® Excel file (i.e., Output.xlsx), by clicking the *Send Results to Excel File (Output.xlsx)* icon or selecting the *Send Results to Excel File (Output.xlsx)* option from the pull-down menu of *Excel* and then this file is opened by Excel by clicking the *Open and Edit Excel File (Output.xlsx)* icon or selecting the *Open Excel File (Output.xlsx)* option from the pull-down menu of *Excel*. WinSpingc is a compiled program that consists of a self-extracting setup file including all the necessary support files (i.e., dll and ocx) for the 32-bit system. By clicking the setup file, the program and its associated files (i.e., support files, help file, data files with the extension of ssg, xls, xlsx and plot files with the extension of grf) are installed into the personal computer (i.e., the directory of C:\Program Files\WinSpingc or C:\Program Files (x86)\WinSpingc) with the Windows XP and later operating systems. An installation of the program into a personal computer with the 64-bit operating system may require the msflexgrd adjustment. This procedure is explained in detail in ESM 2. The self-extracting setup file is 20 Mb and can be obtained from the journal server.

Acknowledgments. We are grateful for constructive comments, contributions and suggestions from Ferdinando Bosi on an earlier draft, which improved the overall quality and clarity of the manuscript and the program structure. We thank Ondrej Nemec and an anonymous reviewer for their constructive reviews. We also thank Jakub K. Plášil, Editor-in-Chief, and Peter Bačík for their editorial handling and valuable contributions.

Electronic supplementary material. The supplemental files for the paper are available online at the Journal website (http://dx.doi.org/10.3190/jgeosci.369).

Tab. 3 Chemical compositions of selected oxyspinel minerals with calculations and classifications by WinSpinge

Row		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
1	SiO_2	0.01	0.02	0.54	0.00	0.00	1.40	0.04	0.00	0.20	0.02	2.98	0.20
2	TiO_2	0.22	0.73	0.00	0.00	0.00	0.00	0.02	0.00	0.00	26.41	1.04	26.30
3	GeO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.00	0.00	0.00	0.00	0.00
4	Al_2O_3	1.02	32.63	0.00	0.00	39.43	0.00	80.70	0.00	0.60	4.83	0.35	1.40
5	Ti_2O_2	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Cr_2O_3	24.99	0.00	0.00	0.00	0.27	0.00	0.01	0.00	0.00	0.00	0.00	0.00
7	V_2O_3	39.98	34.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
8	Fe_2O_3	0.00	0.00	0.00	0.00	17.96	66.24	8.16	0.00	15.30	28.27	0.17	16.50
9	Mn_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.23	0.00
10	Co_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	VO	0.00	23.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	FeO	27.21	0.00	0.00	0.00	0.00	1.96	0.00	63.80	0.00	10.32	0.00	51.70
13	MgO	0.00	7.23	0.00	0.00	0.00	0.24	1.70	0.00	12.30	29.62	23.23	1.80
14	CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
15	MnO	2.31	0.41	0.87	91.38	0.00	0.00	2.49	0.00	36.80	0.76	27.30	0.70
16	CuO	0.00	0.00	0.73	0.00	25.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	ZnO	3.79	0.00	0.00	0.00	17.45	0.00	3.25	0.00	0.00	0.00	1.58	0.00
18	CoO	0.00	0.00	90.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	NiO	0.00	0.00	0.00	0.00	0.00	29.71	0.00	0.00	0.00	0.00	0.00	0.00
20	Na_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
21	K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
22	Li_2O	0.00	0.00	0.00	0.00	0.00	0.00	3.68	0.00	0.00	0.00	0.00	0.00
23	Sb_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.80	0.00	37.03	0.00
24	∑ (wt.%)	99.59	100.06	99.58	98.26	100.12	99.55	100.25	101.76	100.00	100.23	100.91	98.80
25	$FeO_{calculated}$	26.69	0.00	0.00	0.00	0.00	0.00	0.00	55.14	0.00	0.00	0.00	0.00
26	$Fe_2O_{3\ calculated}$	0.58	0.00	0.00	0.00	0.00	0.00	0.00	9.63	0.00	0.00	0.00	0.00
27	$MnO_{calculated}$	0.00	0.00	0.00	30.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	$Mn_2O_{3\ calculated}$	0.00	0.00	0.00	67.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	$CoO_{calculated}$	0.00	0.00	30.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	$Co_2O_{3\ calculated}$	0.00	0.00	67.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	Si	0.0004	0.0006	0.0217	0.0000	0.0000	0.0544	0.0010	0.0000	0.0080	0.0006	0.1084	0.0074
32	Ti	0.0062	0.0165	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000	0.5944	0.0285	0.7353
33	Ge	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8540	0.0000	0.0000	0.0000	0.0000
34	Al	0.0447	1.1565	0.0000	0.0000	1.5158	0.0000	2.3110	0.0000	0.0283	0.1703	0.0150	0.0613
35	Ti^{3+}	0.0000	0.0166	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Cr	0.7345	0.0000	0.0000	0.0000	0.0070	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
37	V^{3+}	1.1916	0.8410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0060
38	Fe^{3+}	0.0162	0.0000	0.0000	0.0000	0.4408	1.9385	0.1492	0.2913	0.4614	0.6364	0.0047	0.4614

Tab. 3 Continued

Row		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
39	Mn^{3+}	0.0000	0.0000	0.0000	2.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2002	0.0000
40	Co^{3+}	0.0000	0.0000	1.9567	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	V^{2+}	0.0000	0.6343	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	Fe^{2+}	0.8298	0.0000	0.0000	0.0000	0.0000	0.0637	0.0000	1.8544	0.0000	0.2582	0.0000	1.6068
43	Mg	0.0000	0.3241	0.0000	0.0000	0.0000	0.0139	0.0616	0.0000	0.7349	1.3209	1.2596	0.0997
44	Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0021	0.0000	0.0000	0.0000	0.0000	0.0000
45	Mn	0.0727	0.0104	0.0296	0.9997	0.0000	0.0000	0.0512	0.0000	1.2492	0.0193	0.8410	0.0220
46	Cu	0.0000	0.0000	0.0221	0.0000	0.6162	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Zn	0.1040	0.0000	0.0000	0.0000	0.4202	0.0000	0.0583	0.0000	0.0000	0.0000	0.0424	0.0000
48	Co^{2+}	0.0000	0.0000	0.9700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	Ni	0.0000	0.0000	0.0000	0.0000	0.0000	0.9294	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0052	0.0000	0.0000	0.0000	0.0000	0.0000
51	K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000
52	Li	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3596	0.0000	0.0000	0.0000	0.0000	0.0000
53	Sb^{5+}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5181	0.0000	0.5003	0.0000
54	∑ "*apfu*"	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000
55	Fe^{3+}/Fe^{2+}	0.02	0.00	0.00	0.00	0.00	30.41	0.00	0.16	0.00	2.46	0.00	0.29
56	$Fe^{3+}/(Fe^{3+}+Fe^{2+})$	0.02	0.00	0.00	0.00	1.00	0.97	1.00	0.14	1.00	0.71	1.00	0.22
57	Cr/(Cr+Al)	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	$Fe^{2+}/(Fe^{2+}+Mg)$	1.00	0.00	0.00	0.00	0.00	0.82	0.00	1.00	0.00	0.16	0.00	0.94
59	$Cr/(Cr+Al+Fe^{3+})$	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	$Fe^{3+}/(Fe^{3+}+Al+Cr)$	0.02	0.00	0.00	0.00	0.22	1.00	0.06	1.00	0.94	0.79	0.24	0.88
61	$Al/(Al+Fe^{3+}+Cr)$	0.06	1.00	0.00	0.00	0.77	0.00	0.94	0.00	0.06	0.21	0.76	0.12
62	Ti/(Ti+Cr+Al)	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.65	0.92
63	$\sum R^{2+}$	1.01	0.97	1.02	1.00	1.04	1.01	0.17	1.85	1.98	1.60	2.14	1.73
64	$\sum R^{3+}$	1.99	2.01	1.96	2.00	1.96	1.94	2.46	0.29	0.49	0.81	0.22	0.53
65	$\sum R^{4+}$	0.01	0.02	0.02	0.00	0.00	0.05	0.00	0.85	0.01	0.59	0.14	0.74
66	$\sum R^{5+}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.50	0.00
67	Dominant A cation	Fe^{2+}	V^{2+}	Co^{2+}	Mn^{2+}	Cu^{2+}	Ni^{2+}	$Li_{0.5}Al_{0.5}$	Ge^{4+}	$(Fe^{3+})_{0.5}(Sb^{5+})_{0.5}$	Ti^{4+}	$(Mn^{3+})_{0.5}(Sb^{5+})_{0.5}$	Ti^{4+}
68	Dominant B cation	V^{3+}	Al^{3+}	Co^{3+}	Mn^{3+}	Al^{3+}	Fe^{3+}	Al^{3+}	Fe^{2+}	Mn^{2+}	Mg^{2+}	Mg^{2+}	Fe^{2+}
69	Spinel Group	Oxy	Oxy	Oxy	Oxy	Oxy	Oxy	Oxy	Oxy	Oxy	Oxy	Oxy	Oxy
70	Spinel Subgroup	(3-2)	(3-2)	(3-2)	(3-2)	(3-2)	(3-2)	(3-2)	(4-2)	(4-2)	(4-2)	(4-2)	(4-2)
71	Spinel Species	Cou	Dgt	Gui	Hsm	Tag	Trv	Ckc	Bng	Fps	Qnd	Teg	Uspl

Samples of S1 = from Kompanchenko (2020), S2 = from Cámara et al. (2019), S3 = from Lei et al. (2022), S4, S5, S6, S8, S10, S11 and 12 = from Handbook of Mineralogy (Anthony et al. 2001–2005), S7 = from Rao et al. (2022), S9 = from Dunn et al. (1988); The formulae were recalculated to 3 cations and 4 oxygens; Calculated oxides in rows 25 to 30 from total FeO, MnO and CoO (wt.%) contents were carried out on the basis of stoichiometric constraints using the Droop's (1987) method; "*apfu*" = Atoms per formula unit; R^{2+} = Total divalent cations, R^{3+} = Total trivalent cations, R^{4+} = Total tetravalent cations, R^{5+} = Total pentavalent cations; Oxy = Oxyspinel; (3-2) = Spinel subgroup; (4-2) = Ulvöspinel subgroup; Cou = Coulsonite, Dgt = Dellagiustaite, Gui =Guite, Hsm = Hausmannite, Tag = Thermaerogenite, Trv = Trevorite, Ckc = Chukochenite, Bng = Brunogeierite, Fps = Filipstadite, Qnd = Qandilite, Teg = Tegengrenite, Uspl = Ulvöspinel.

Tab. 4 Chemical compositions of selected thiospinel minerals with calculations and classifications by WinSpingc

Row		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
1	Cu	20.20	21.03	9.95	0.14	0.00	0.00	0.08	8.79	0.00	0.08	3.16	3.81
2	Ag	0.00	0.00	0.00	24.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Cd	0.00	0.00	0.00	0.22	19.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Fe	0.60	0.47	1.00	6.28	1.71	20.10	4.50	1.30	3.98	1.16	3.22	1.58
5	Mn	0.00	0.00	0.00	0.00	0.00	0.00	15.80	0.00	0.00	0.03	0.00	0.00
6	Zn	0.00	0.17	0.00	0.37	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Ge	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Co	38.60	0.00	2.60	0.00	0.00	0.00	0.00	40.71	0.63	38.23	20.36	0.00
9	Ni	0.30	0.00	0.33	0.00	0.00	0.00	0.09	7.35	54.30	19.27	31.24	0.00
10	Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	12.80
11	Bi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00
12	Cr	0.00	29.01	0.00	0.00	0.00	35.91	36.20	0.00	0.00	0.00	0.00	0.00
13	V	0.00	5.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	In	0.00	0.00	0.00	0.05	49.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Sb	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	As	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
17	Sn	0.00	0.00	0.00	41.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Ir	0.00	0.00	25.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.49
19	Pd	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Pt	0.00	0.00	36.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.67
21	Rh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.19
22	Se	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Te	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	S	41.20	43.25	23.47	28.16	27.53	42.69	44.30	41.43	41.09	41.05	42.43	21.68
25	∑ (%)	100.90	100.07	99.80	100.85	99.79	98.70	100.97	99.58	100.00	100.99	100.41	100.22
26	Cu	0.9900	0.9810	0.8560	0.0100	0.0000	0.0000	0.0040	0.4280	0.0000	0.0040	0.1500	0.3550
27	Ag	0.0000	0.0000	0.0000	1.0300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Cd	0.0000	0.0000	0.0000	0.0090	0.8280	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	Fe	0.0330	0.0250	0.0980	0.5120	0.1430	1.0810	0.2330	0.0720	0.2220	0.0650	0.1740	0.1670
30	Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8330	0.0000	0.0000	0.0020	0.0000	0.0000
31	Zn	0.0000	0.0080	0.0000	0.0260	0.0550	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	Ge	0.0000	0.0000	0.0000	0.0000	0.0190	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	Co	2.0390	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	2.1390	0.0330	2.0270	1.0440	0.0000
34	Ni	0.0160	0.0000	0.0310	0.0000	0.0000	0.0000	0.0040	0.3880	2.8880	1.0260	1.6090	0.0000
35	Pb	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0070	0.0000	0.3650
36	Bi	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0090	0.0000	0.0000
37	Cr	0.0000	1.6550	0.0000	0.0000	0.0000	2.0750	2.0160	0.0000	0.0000	0.0000	0.0000	0.0000
38	V	0.0000	0.3410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

39	In	0.0000	0.0000	0.0000	0.0020	2.0090	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Sb	0.0000	0.0020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	As	0.0000	0.0080	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0040	0.0000	0.0000	0.0000
42	Sn	0.0000	0.0000	0.0000	1.5820	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	Ir	0.0000	0.0000	0.7170	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.3390
44	Pd	0.0000	0.0000	0.0230	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	Pt	0.0000	0.0000	1.0300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2930
46	Rh	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4130
47	Se	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	Te	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	S	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
50	∑ "*apfu*"	7.0800	7.0200	7.0000	7.1700	7.0500	7.1600	7.0900	7.0300	7.1400	7.1400	6.9800	6.9300	
51	Dominant A cation	Cu	Cu	Cu	Ag	Cd	Fe	Mn	Co	Ni	Ni	Co	Pb	
52	Dominant B cation	Co	$(Cr^{3+}Cr^{4+})$	$(Ir^{3+}Pt^{4+})$	$(Fe^{2+})_{0.5}(Sn^{4+})_{1.5}$	In	Cr	Cr	Co	Ni	Co	Ni	Ir	
53	Spinel Group	Thio	Thio	Thio	Thio	Thio	Thio	Thio	Thio	Thio	Thio	Thio	Thio	
54	Spinel Subgroup	(1-3.5)	(1-3.5)	(1-3.5)	(1-3.5)	(1-3.5)	(2-3)	(2-3)	(2-3)	(2-3)	(2-3)	(2-3)	(2-3)	
55	Spinel Species	Cli	Ckal	Mla	To	Cad	Dau	Jgs	Lin	Pld	Gmm	Seg	Xin	

Samples of S1, S2, S3, S5, S6, S7, S8, S9, S11 and S12 = from Handbook of Mineralogy (Anthony et al. 2001–2005), S4 = from Yajima et al. (1991), S10 = from Škácha et al. (2021); The formulae were recalculated based on 7 "*apfu*"; Thio = Thiospinel; (1-3.5) = Carrollite subgroup; (2-3) = Linnaeite subgroup; Cli = Carrollite, Ckal = Cuprokalininite, Mla = Malanite, To = Toyohaite, Cad = Cadmoindite, Dau = Daubréelite, Jgs = Joegoldsteinite, Lin = Linnaeite, Pld = Polydymite, Gmm = Grimmite, Seg = Siegenite, Xin = Xingzhongite.

Tab. 5 Chemical compositions of selected selenospinel minerals with calculations and classifications by WinSpingc

Row		S1	S2	S3
1	Cu	12.70	13.01	0.00
2	Fe	0.00	0.27	0.00
3	Co	17.70	6.66	6.40
4	Ni	6.90	16.98	29.50
5	Pb	0.00	0.00	0.00
6	S	0.00	1.04	0.00
7	Se	62.40	61.91	64.40
8	∑ (%)	99.70	99.87	100.30
9	Cu	1.0120	1.0440	0.0000
10	Fe	0.0000	0.0250	0.0000
11	Co	1.5200	0.5770	0.5330
12	Ni	0.5950	1.4760	2.4650
13	Pb	0.0000	0.0000	0.0000
14	S	0.0000	0.1650	0.0000
15	Se	4.0000	4.0000	4.0000
16	∑ "*apfu*"	7.1300	7.2900	7.0000
17	Dominant A cation	Cu	Cu	Ni
18	Dominant B cation	Co, Ni	Ni	Ni
19	Spinel Group	Seleno	Seleno	Seleno
20	Spinel Subgroup	(1-3.5)	(1-3.5)	(2-3)
21	Spinel Species	Ty	Nty	Trü

Samples of S1 and S3 = from Handbook of Mineralogy (Anthony et al. 2001–2005), S2 = from Förster et al. (2019); The formulae were recalculated based on7 atoms per formula unit ("*apfu*"); Seleno = Selenospinel; (1-3.5) = Tyrrellite subgroup; (2-3) = Bornhardtite subgroup; Ty = Tyrrellite, Nty = Nickeltyrrellite, Trü = Trüstedtite.

References

Al-Juboury AI, Ghazal MM, McCann T (2009) Detrital chromian spinels from Miocene and Holocene sediments of northern Iraq: provenance implications. J Geosci 54: 289–300

Anthony JW, Bideaux RA, Bladh KW, Nichols MC (2001–2005) Handbook of Mineralogy, Mineralogical Society of America, Chantilly, VA 20151–1110, USA. http://www.handbookofmineralogy.org/

Antonini AS, Ganuza ML, Ferracutti G, Gargiulo MF, Matković K, Gröller E, Bjerg EA, Castro SM (2020) Spinel web: an interactive web application for visualizing the chemical composition of spinel group minerals. Earth Sci Inform 14: 521–528

Arai S (1978) Formation of the chlorite corona around chromian spinel in peridotite and its significance. Geosci Rept Shizuoka Univ 3: 9–15

Arai S (1992) Chemistry of chromium spinel in volcanic rocks as a potential guide to magma history. Mineral Mag 56: 173–184

Arai S (1994a) Characterization of spinel peridotites by olivine spinel compositional relationships: Review and interpretation. Chem Geol 113: 19–204

Arai S (1994b) Compositional variation of olivine-chromain spinel in Mg-rich magmas as a guide to their

residual spinel peridotites. J Volcanol Geotherm Res 59: 279–294

Arai S, Shimizu Y, Ismail SA, Ahmad AH (2006) Low T formation of high-Cr spinel with apparently primary chemical characteristics within podiform chromitite from Rayat, northeastern Iraq. Mineral Mag 70: 499–508

Arai S, Okamura H, Kadoshima K, Tanaka C, Suzuki K, Ishimaru S (2011) Chemical characteristics of chromian spinel in plutonic rocks: implications for deep magma processes and discrimination of tectonic setting. Isl Arc 20; 125–137

Barkov AY, Martin RF, Halkoaho TAA, Poirier G (2000) The mechanism of charge compensation in Cu–Fe–PGE thiospinels from the Penikat layered intrusion, Finland. Amer Mineral 85: 694–697

Barnes SJ, Roeder PL (2001) The range of spinel compositions in terrestrial mafic and ultramafic rocks. J Petrol 42: 2279–2302

Baxter AT, Aitchison JC, Ali JR, Sik-Lap Chan J, Nagi Chan GH (2016) Detrital chrome spinel evidence for a Neotethyan intra-oceanic island arc collision with India in the Paleocene. J Asian Earth Sci 128: 90–104

Beard JS, Tracy RT (2002) Spinels and other oxides in Mn-rich rocks from the Hutter Mine, Pittsylvania County, Virginia, U.S.A.: Implications for miscibility and solvus relations among jacobsite, galaxite, and magnetite. Amer Miner 87: 690–698

Beckett-Brown CE, McDonald AM, Zhe W (2018) A crystallographically oriented intergrowth of siegenite ($CoNi_2S_4$) and millerite from the Morokweng impact structure, South Africa: chemistry, texture, and origin. Canad Mineral 56: 705–722

Bhat IM, Ahmad T, Rao DVS (2019) Alteration of primary Cr-spinel mineral composition from the Suru Valley ophiolitic peridotites, Ladakh Himalaya: Their low-temperature metamorphic implications. J Earth Syst Sci 128: 188, 1–14

Biagioni C, Pasero M (2014) The systematics of the spinel-type minerals: An overview. Amer Miner 99: 1254–1264

Bosi F (2019) Chemical and structural variability in cubic spinel oxides. Acta Crystalogr B75: 279–285

Bosi F, Biagioni C, Pasero M (2019a) Nomenclature and classification of the spinel supergroup. Eur J Mineral 31: 183–192

Bosi F, Biagioni C, Oberti R (2019b) On the chemical identification and classification of minerals. Minerals 9: 591. doi:10.3390/min9100591

Cámara F, Bindi L, Pagano A, Pagano R, Gain SEM, Griffin WL (2019) Dellagiustaite: a novel natural spinel containing V^{2+}. Minerals: 9: 4. doi:10.3390/min9010004

Cookenboo HO, Bustin RM, Wilks KR (1997) Detrital chromian spinel compositions used to reconstruct the tectonic setting of provenance: Implications for orogeny in the Canadian cordillera. J Sediment Res. 67: 116–123

Dick HJB, Bullen T (1984) Chromian spinel as a petrogenetic indicator in abyssal and alpine type peridotites and spatially associated lavas. Contrib Mineral Petrol 86: 54–76

Droop GTR (1987) A general equation for estimating Fe^{3+} concentrations in ferromagnesian silicates and oxides from microprobe analyses using stoichiometric criteria. Mineral Mag 51: 431–435

Dunn PJ, Peacor DR, Criddle AJ, Stanley CJ (1988) Filipstadite, a new Mn-Fe^{3+}-Sb derivative of spinel, from Långban, Sweden. Amer Miner 73: 413–419

Essene EJ, Peacor DR (1983) Crystal chemistry and petrology of coexisting galaxite and jacobsite and other spinel solutions and solvi. Amer Minerl 68: 449–455

Förster H-J, Ma C, Grundmann G, Bindi L, Stanley CJ (2019) Nickeltyrrellite, $CuNi_2Se4$, a new member of the spinel supergroup from El Dragón, Bolivia. Canad Mineral 57: 637–646

Gamal EL Dien H, Arai S, Doucet LS, Li ZX, Kil Y, Fougerouse D, Reddy SM, Saxey DW, Hamdy M (2019) Cr-spinel records metasomatism not petrogenesis of mantle rocks. Nat Commun 10: 5103. 1–12

GanuzA ML, Castro SM, Ferracutti G, Bjerg EA, Martig SR (2012) Spinelviz: an interactive 3d application for visualizing spinel group minerals. Comput Geosci 48: 50–56

Ganuza ML, Ferracutti G, GargiulO MF, Castro SM, Bjerg E, Gröller E, Matković K (2014) The spinel explorer–interactive visual analysis of spinel group minerals. IEEE Trans Vis Comput Graph 20: 1913–1922

Gargiulo MF, Bjerg EA, Mogessie A (2013) Spinel group minerals in metamorphosed ultramafic rocks from Río de Las Tunas belt, Central Andes, Argentina. Geol Acta 11: 133-148

Gawlick HJ, Sudar M, Missoni S, Aubrecht R, Schlagintweit F, Jovanović D, Mikuš T (2020) Formation of a Late Jurassic carbonate platform on top of the obducted Dinaridic ophiolites deduced from the analysis of carbonate pebbles and ophiolitic detritus in southwestern Serbia. Int J Earth Sci 109: 2023–2048

Ghosh B, Morishita T, Bhatta K (2013) Significance of chromian spinels from the mantle sequence of the Andaman Ophiolite, India: Paleogeodynamic implications. Lithos 164–167: 86–96

Harstad TS, Mørk MBE, Slagstad T (2020) The importance of trace element analyses in detrital Cr-spinel provenance studies: An example from the Upper Triassic of the Barents Shelf. Basin Res 33: 1017–1032

Heimann A, Spry PG (2005) Zincian spinel associated with metamorphosed Proterozoic base-metal sulfide occurrences, Colorado: a re-evaluation of gahnite composition as a guide in exploration. Canad Mineral 43: 601–622

Hwang SL, Shen P, Yui TF, Chu HT, IIzuka Y, Schertl HP, Spengler D (2022) Chihmingite, IMA 2022-010,

in: CNMNC Newsletter 67, Eur J Mineral 34: 59–364. doi.org/10.5194/ejm-34-359-2022, 2022.

Irvine TN (1965) Chromium spinels as a petrogenetic indicator. Part 1 Theory. Canad J Earth Sci 2: 648–673

Irvine TN (1967) Chromium spinels as a petrogenetic indicator. Part 2 Petrologic applications. Canad J Earth Sci 4: 71–103

Irvine TN, Findlay TC (1972) Alpine-type peridotite with particular reference to the Bay of Islands Igneous Complex. Publ Earth Phys Branch Dept Energ Mines Resour 42: 97–140

Johan Z, Ohnenstetter D (2010) Zincochromite from the Guaniamo River diamondiferous placers, Venezuela: evidence of its metasomatic origin. Canad Mineral 48: 361–374

Kamenetsky VS, Crawford AJ, Meffre S (2001) Factors controlling chemistry of magmatic spinel: An empirical study of associated olivine, Cr-spinel and melt inclusions from primitive rocks. J Petrol 42: 655–671

Kompanchenko AA (2020) Coulsonite FeV_2O_4 – A rare vanadium spinel group mineral in metamorphosed massive sulfide ores of the Kola Region, Russia. Minerals 10: 843. doi:10.3390/min1010084342

Leblanc M, Nicolas A (1992) Ophiolitic chromitities. Int Geol Rev 34: 653–686

Lee YII (1999) Geotectonic significance of detrital chromian spinel: a review. Geosci J 3: 23–29

Lei Z, Chen X, Wang J, Huang Y, Du F, Yan Z (2022) Guite, the spinel-structured $Co^{2+}Co^{3+}{}_2O_4$, a new mineral from the Sicomines copper–cobalt mine, Democratic Republic of Congo. Mineral Mag 1–8, doi:10.1180/mgm.2022.27

Lenaz D, Princivalle F (2005) The crystal chemistry of detrital chromian spinel from the southeastern Alps and outer Dinarides: the discrimination of supplies from areas of similar tectonic setting? Canad Mineral 43: 1305–1314

Lippo J, Vuollo J, Nykänen V, Piirainen T (1994) Chromite compositions as evidence for an Archaean ophiolite in the Kuhmo Greenstone Belt in Finland. Bull Geol Soc Finland 66: 3–18

Mekhonoshin AS, Kolotilina TB, Doroshkov AA, Pikiner EE (2020) Compositional variation of Cr-spinel in high-Mg intrusions of the Primorsky Ridge (Western Baikal Region, Russia). Minerals 10: 608. doi:10.3390/min10070608

Nekrasov IY, Lennikov AM, Zalishchak BL, Oktyabrsky RA, Ivanov VV, Sapin VI, Taskaev VI (2005) Compositional variations in platinum-group minerals and gold, Konder Alkaline-Ultrabasic Massif, Aldan Shield, Russia. Canad Mineral 43: 637–654

Oktyabrsky RA, Shcheka SA, Lennikov AM, Afanasyeva TB (1992) The first occurrence of qandilite in Russia. Mineral Mag 56: 385–389

Ostwald J (1978) Linnaeite series minerals from the Kalgoorlie district, Western Australia. Mineral Mag 42: 93–98

Pascal ML, Fonteilles M, Boudouma O (2011) Qandilite from Vesuvius skarn ejecta: conditions of formation and miscibility gap in the ternary spinel – qandilite – magnesioferrite. Canad Mineral 49: 459–485

Pekov IV, Sandalov FD, Koshlyakova NN, Vigasina MF, Polekhovsky YS, Britvin SN, Sidorov EG, Turchkova AG (2018) Copper in natural oxide spinels: The new mineral Thermaerogenite $CuAl_2O_4$, Cuprospinel and Cu-enriched varieties of other spinel-group members from fumaroles of the Tolbachik Volcano, Kamchatka, Russia. Minerals 8: 498. doi:10.3390/min811049849: 459–485

Rao C, Gu X, Wang R, Xia Q, Cai Y, Dong C, Hatert F, Hao Y (2022) Chukochenite, $(Li_{0.5}Al_{0.5})Al_2O_4$, a new lithium oxyspinel mineral from the Xianghualing skarn, Hunan Province, China. Amer Miner 107: 842–847

Sack RO, Ghiorso MS (1991) Chromian spinels as petrogenetic indicators: thermodynamics and petrological applications. Amer Miner 76: 827–847

Sharygin VV, Kamenetsky VS, Zhitova LM, Belousov AB, Abersteiner A (2018) Copper-containing magnesioferrite in vesicular trachyandesite in a lava tube from the 2012–2013 Eruption of the Tolbachik Volcano, Kamchatka, Russia. Minerals 8: 514. doi:10.3390/min811051476: 827–847

Škácha P, Sejkora J, Plášil J, Dolníček Z, Ulmanová J (2021) Grimmite, $NiCo_2S_4$, a new thiospinel from Příbram, Czech Republic. Eur J Mineral 33: 175–187

Stalder M, Rozendaal A (2005) Calderite-rich garnet and franklinite-rich spinel in amphibolite-facies hydrothermal sediments, Gamsberg Zn–Pb deposit, Namaqua Province, South Africa. Canad Mineral 43: 585–599

Stevens RE (1944) Compositions of some chromites of the western hemisphere. Amer Miner 29: 1–34

Voigt M, von der Handt A (2011) Influence of subsolidus processes on the chromium number in spinel in ultramafic rocks. Contrib Mineral Petrol 162: 675–689

Warr LN (2021) IMA–CNMNC approved mineral symbols. Mineral Mag 85: 291–320

Yajima J, Ohta E, Kanazawa Y (1991) Toyohaite, $Ag_2FeSn_3S_8$, a new mineral. Mineral J 15: 222–232

Yavuz F (1999) CHROMITE: A program to process electron microprobe data from Cr-rich spinels. J Trace Microprobe Tech 17: 17–23

Yavuz F (2001) PYROX: A computer program for the IMA pyroxene classification and calculation scheme. Comput Geosci 27: 97–107

Yavuz F (2003) Evaluating micas in petrologic and metallogenic aspect: I-definitions and structure of the computer program MICA$^+$. Comput Geosci 29: 1203–1213

Yavuz F (2007) WinAmphcal: a windows program for the IMA-04 amphibole classification. Geochem Geophys Geosyst 8: Q01004, 1–12

Yavuz F (2013) WinPyrox: A Windows program for pyroxene calculation classification and thermobarometry. Amer Miner 98: 1338–1359

Yavuz F (2021) WinMIgob: A Windows program for magnetite–ilmenite geothermometer and oxygen barometer. J Geosci 66: 51–70

Yavuz F, Döner Z (2017) WinAmptb: A Windows program for calcic amphibole thermobarometry. Period Mineral 87: 135–167

Yavuz F, Yavuz EV (2022) A Windows program for feldspar group thermometers and hygrometers. Period Mineral 91: 63–87

Yavuz F, Yildirim DK (2018a) A Windows program for pyroxene-liquid thermobarometry. Period Mineral 87: 149–172

Yavuz F, Yildirim DK (2018b) A Windows program for calculation and classification of epidote-supergroup minerals. Period Mineral 87: 269–285

Yavuz F, Yildirim DK (2020) WinGrt, a Windows program for garnet supergroup minerals. J Geosci 65: 71–95

Yavuz F, Karakaya N, Yildirim DK, Karakaya MÇ, Kumral M (2014) A Windows program for calculation and classification of tourmaline-supergroup (IMA-2011). Comput Geosci 63: 70–87

Yavuz F, Kumral M, Karakaya N, Karakaya MÇ, Yildirim DK (2015) A Windows program for chlorite calculation and classification. Comput Geosci 81: 101–113