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WinEudclas, a Windows program for eudialyte-group minerals

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ABSTRACT

A Microsoft® Visual Basic software, WinEudclas, has been developed to calculate the chemical compositions of eudialyte-group minerals based on data obtained from wet-chemical and electron-microprobe analyses. WinEudclas currently evaluates 32 valid mineral species using the Commission on New Minerals, Nomenclature and Classification (CNMMC) of the International Mineralogical Association (IMA) nomenclature scheme for the eudialyte-group minerals, with the general formula $[N(1)N(2)N(3)N(4)N(5)]_3M1_6M2_3M3M4Z_3(Si_9O_{27})_2(Si_3O_9)_2Ø_{4-6}X1X2$. The program recalculates and estimates the chemical formulas of eudialyte-group species based on 72 oxygen atoms, with the total of Si+Al+Ti+Zr+Hf+Nb+Ta+W = 29 atoms per formula unit normalization approach. WinEudclas operates in five stages: (1) it estimates cation and anion contents provided by input chemical data; (2) it determines the zirconium- and zirconium-titanium eudialytes; (3) it assigns the Ca-rich and Ca-poor eudialytes; (4) it specifies the eudialyte subgroups and eudialyte series along with various variants; and (5) it classifies the eudialyte-group species into an appropriate group and series such as ferrokentbrooksite subgroup and feklichevite series. WinEudclas allows users to: (1) enter up to 40 input variables for mineral-chemical analyses; (2) type and load multiple eudialyte group mineral compositions in the data entry section; (3) edit and load the Microsoft® Excel files used in calculating, classifying, and naming the eudialyte-group minerals, and (4) store all the calculated parameters in the output of a Microsoft® Excel file for further data 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: eudialyte group; fengchengite subgroup; ferrokentbrooksite subgroup; manganokhomyakovite subgroup; sergevanite subgroup; nomenclature; classification; software.

INTRODUCTION

Eudialyte $[Na_{15}Ca_6Fe_3^{2+}Zr_3Si_{25}O_{73})(O,OH,H_2O)_3(Cl,OH)_2]$, which was discovered over 200 years ago in the Ilímaussaq alkaline massif in Greenland, is of both scientific and economic interest due to its key role in the mineralogy and geochemistry as perspective indicators of the conditions of petrogenetic processes by crystallizing through a range of magmatic to hydrothermal conditions as well as for the extraction of high-field-strength elements (e.g., Zr) and critical rare-earth elements (REEs; e.g., Nd) (Mikhailova et al., 2020; Borst et al., 2020; Schilling et al., 2011). Consequently, minerals of the eudialyte group, characterized by its variable rare earth, zirconium, and niobium contents, represent essential materials for modern

technologies in a variety of uses such as clean energy, durable alloys, permanent magnets, catalysts, phosphors for lighting and digital screens, rechargeable batteries, and ion-exchange media due to the cage-like property of the structure (Brooks, 2022). The main advantage of sourcing rare-earth elements from eudialyte-group minerals (EGM) is their ease of processing, as they dissolve easily in simple acids and relatively lower radioactive uranium and thorium levels (Mikhailova et al., 2022). The EGM is a diverse group of minerals found in agpaitic rocks at ~100 locations globally, consisting of 32 IMA-approved end members due to wide chemical variations and different isomorphous substitution schemes. The EGM represent a significant constituent of specific peralkaline rock types. They are alkali, HFSE-bearing cyclosilicates that may incorporate a diverse range of elements, including Na, Ca, Zr, Si, Ti, Fe, Mn, REE, Y, Nb, W, Hf, K, and Sr, along with Cl, F, H_2O, and OH groups within their complex trigonal zeolite-like structure (Johnsen et al. 2001, 2003a; Mikhailova et al. 2022). The EGM are common in evolved SiO_2-undersaturated syenites but rare in peralkaline granites. Although minerals of the eudialyte group are usually found in intraplate environments with crystallization trend at various fractionation stages, newly described members of this group are typically occurring in rare pegmatites, late-stage veins as well as in metamorphic rocks (Schilling et al., 2011; Estrade et al., 2018; Marks et al., 2020). The precepts accepted by the International Mineralogical Association- Commission on New Minerals, Nomenclature and Classification (IMA-CNMNC) for a new mineral species belonging to the eudialyte group are based on the general crystal-chemical rules of the predominance elements at one or several key sites (Rastsvetaevaa and Chukanov, 2012). Considering the hierarchical crystal-chemical approach for the classification of EGM by Rastsvetaeva and Chukanov (2012), Mikhailova et al. (2022) proposed a new diagnostic scheme using only the chemical composition for the eudialyte-group minerals in five classification steps within the six variants (e.g., *T*+*T* eudialytes), seventeen subgroups (e.g., eudialyte subgroup), and four series (e.g., davinciite series).

Various computer programs for calculating and classifying rock-forming silicates and minerals have been developed over the past two decades (e.g., Yavuz, 1999, 2003, 2013; Yavuz et al., 2014, 2015; Yavuz and Yıldırım, 2018, 2020; Yavuz, 2021; Yavuz and Yavuz, 2022, 2023a,b, 2024; Yavuz, 2024a,b; Janoušek et al., 2024; Yavuz, 2025 a,b,c; Siebach et al., 2026). However, few are useful for the EGM according to the latest IMA report, aside from an Excel spreadsheet based on electron microprobe analyses that overlooks different iron valence states and undetermined H_2O contents, as noted by Pfaff et al. (2010). Taking this situation into consideration, a computer program called WinEudclas has been developed using the Microsoft® Visual Basic programming language. It can be used to calculate the chemical formulas from up to 200 analyses obtained from both wet-chemical and electron-microprobe techniques. The program calculates the compositional formulas of EGM on the basis of 72 oxygen atoms per formula unit (apfu) with the total of Si+Al+Ti+Zr+Hf+Nb+Ta+W=29 (apfu) normalization approach [Tot29 (apfu)]. In addition, WinEudclas allows users to select several normalization options among one of several normalization options, preferred by some researchers in the literature, including Si+Nb=26 (apfu), Si+Al=26 (apfu), Si=25 (apfu), Si=26 (apfu), and Si+Al+Nb=26 (apfu) from the pull-down menu of *Normalization* in the *Start-up Screen* or *Data Entry Screen* for the compositional formulas of EGM. The calculation procedures applied by the program are conform to the currently accepted IMA nomenclature scheme by Johnsen et al. (2003a). However, the systematic classification is carried out according to the principles proposed by the diagnostic approach proposed by Mikhailova et al. (2022). WinEudclas also considers 15 new EGM, including amableite-(Ce), andrianovite, davinciite, and voronkovite that post-date the IMA report.

Eudialyte-group minerals nomenclature

According to a report from the Eudialyte Nomenclature Subcommittee (ENS), Johnsen et al. (2003a) considered three different approaches for the nomenclature scheme of the eudialyte-group minerals, including a hierarchical system with root names modified by the use of modifiers and Levinson suffixes, a unique-name system with the use of modifiers with or without Levinson suffixes, and a system based on the Linnean principle as used in the biological world. Among these three distinct principles for naming minerals, it is advisable to use conventional unique names for the eudialyte-group minerals, incorporating a maximum of one cation prefix that specifically pertains to the *M*(2) site (Johnsen et al., 2003a). Later, Bulakh and Petrov (2004) presented a formal hierarchical systematics of eudialytes that was primarily based on chemical composition, neglecting intricate crystal-chemical characteristics such as failing to account for the genetic and structural attributes of any given sample. Pfaff et al. (2010) proposed an enhanced site assignment scheme that utilizes the IMA-approved end-members and considers various structural units of the EGM. Their user-friendly calculation method, accompanied by an Excel spreadsheet, is based solely on electron microprobe analyses without factoring in different valence states of iron and manganese or undetermined H_2O contents. Rastsvetaeva and Chukanov

(2012) further proposed a crystal-chemical approach for EGM that enables a consistent classification of known EGM along with the prediction of potentially new species as well as practical implications for ion-exchange properties and the concentration of rare elements. Most recently, Mikhailova et al. (2022) presented a diagnostic scheme for the members of the eudialyte group, based only on chemical composition. Classification involves five consecutive steps, each of which evaluates the content of a species-forming element without applying a time-consuming crystallographic investigation and allowing for the incorporation of new members without changing their hierarchical structure.

The IMA-accepted formula for the eudialyte-group minerals can be written as $[N(1)N(2)N(3)N(4)N(5)]_3M1_6M2_3M3M4Z_3(Si_9O_{27})_2(Si_3O_9)_2Ø_{4\text{-}6}X1X2$, where N(1-5)= Extra-framework cations including mainly Na^+ or H_3O^+, sometimes with species-defining H_2O, K^+, Ca^{2+}, Sr^{2+}, Mn^{2+} or REE^{3+} as well as minor H^+ or Ba^{2+}; *M*1=Ca^{2+}, Na^+, Fe^{2+}, Mn^{2+} and REE^{3+}; *M*2=Na^+, Fe^{2+}, Mn^{2+}, Fe^{3+} or Zr, occurring between rings of $M1O_6$ octahedra; *M*3 and *M*4=$^{[4]}$Si, $^{[4]}$Nb, $^{[4]}$W or $^{[4]}$Ti atoms occurring at the centers of the Si_9O_{27} rings; *Z*=Zr or Ti; Ø, *X*1 and *X*2= Additional extra-framework anions such as OH^-, Cl^- , F^-, O^{2-}, CO_3^{2-}, SO_4^{2-} and S^{2-} and water molecules (Chukanov et al., 2026). The eudialyte-group minerals are trigonal, with crystallizing in space groups *R*3*m*, $R\bar{3}m$ or *R*3, and the unit-cell parameters *a*=14.1-14.2 and *c* = 30.0-30.8 or ~60 Å. They have crystal structures that are characterized by heteropolyhedral frameworks that include $[Si_9O_{27}]$ and $[Si_3O_9]$ tetrahedral rings, six-membered $[M1_6O_{24}]$ rings of edge-sharing $M1O_6$ octahedra (where *M*1 can be Ca, Na, REE, Mn, or Fe^{2+}), linked by ZO_6 octahedra (*Z*=Zr, Ti) and $M2O_n$ polyhedra (*M*2=Fe^{2+}, Fe^{3+}, Mn, Zr, Na; *n*= 4-7). The centers of the $[Si_9O_{27}]$ rings may contain $^{[4]}$Si, $^{[6]}$Nb, $^{[6]}$W, or $^{[6]}$Ti atoms. Extra-framework cations such as Na^+, K^+, Ca^{2+}, Sr^{2+}, Mn^{2+}, REE^{3+}, H_3O^+ are found at five sites (*N*1-5), while extra-framework anions like OH^-, Cl^-, F^-, O^{2-}, CO_3^{2-}, SO_4^{2-}, S^{2-}) and water molecules occupy the *X*1 and *X*2 sites (Kovalskaya et al., 2023; Chukanov et al., 2026).

The diagnostic method by Mikhailova et al. (2022) involves normalizing the formula coefficients of specific elements (i.e., Si, Al, Ti, Zr, Hf, Nb, Ta, W) to a total of 29 (apfu) [i.e., Tot29 (apfu)] and comprises five sequential steps, each designed to assess the characteristics of a species-forming element. In the first step, the required adjustments are implemented for Zr and Ti content (apfu) at the *Z* site. To determine the Zr and Ti at this site, three scenarios are considered: (*i*) Zr fully occupies the *Z* site; (*ii*) Ti fully occupies the Z site; (*iii*) Both Zr and Ti occupy the site in approximately equal concentrations. As examples, the Zr content should be 0.75<Zr<2.25 (apfu) in dualite, Zr<0.75 (apfu) in alluaivite, and Zr>2.25 (apfu) in other minerals. Thus, the eudialyte group is initially categorized into two types: zirconium-titanium-dominant eudialytes, which include "24-layer" dualite and alluaivite, and zirconium-dominant eudialytes, comprising all "12-layer" minerals as well as "24-layer" rastsvetaevite and labyrintite. The second step involves assessing the Ca content at the *M*(1) site, where calcium is typically the main element, with Mn and REE as common substitutes. For calcium to dominate at the *M*(1) site, it must exceed 4.5 (apfu). This threshold differentiates between Ca-rich zirconium eudialytes [Ca>4.5 (apfu)] and Ca-poor zirconium eudialytes [Ca≤4.5 (apfu)]. The third step involves the occupation of the *M*(3) and *M*(4) sites. The Ca-rich zirconium eudialytes are categorized into *T*+*T*, *T*+Nb, *T*+W, and *T*+□ (vacancy) types, while Ca-poor zirconium eudialytes are classified as *T*+*T*, *T*+Nb, and □+□ types. In the fourth step, the occupation of the *M*(2) as well as the *M*(1) and *M*(2) sites for Ca-rich (i.e., eudialyte, fengchengite, manganoeudialyte, aqualite, ferrokentbrooksite, siudaite, georgbarsanovite, khomyakovite, manganokhomyakovite and mogovidite subgroups) and Ca-poor (i.e., ikranite, oneillite, raslakite, sergevanite and voronkovite subgroups) Zr eudialytes is carried out, respectively. The final step involves distinguishing members of the eudialyte group by examining the occupancy of the *N* sites, particularly using the values of ^{N}Na, ^{N}Ca, K, Sr, and ^{N}REE (apfu) to identify specific series within certain subgroups. According to Mikhailova et al. (2022), the diagnostic scheme for the eudialyte-group minerals allows the addition of new members without altering their hierarchical structure. It does not require complete empirical formulas but follows specific rules, such as the order of filling the *M*(1) position when calcium is below 6 (apfu). Many crystal structure positions, like the *M*3 and *M*4 sites, are filled statistically, necessitating a crystal structural analysis to facilitate development of an accurate empirical formula. Thus, approach enables navigation through the diverse range of EGM using somewhat limited chemical composition data.

PROGRAM DESCRIPTION

WinEudclas is a user-friendly, compiled program package (≈11 MB) developed for personal computers running on the Microsoft® Windows operating system with XP and later and ≥512 MB RAM. The program first calculates the cation and anion values (in apfu) from analyses (wt%) made on eudialyte group by means of wet-chemical or electron-microprobe techniques and then uses these to classify the mineral into the IMA-approved species (see Table 1). A list of the calculation steps in the *Calculation Screen* and in the output of a Microsoft Excel file developed by the program is given in Table 2.

Table 1. A list of the IMA-approved species in the eudialyte-group minerals (revised from Mikhailova et al., 2022).

Eudialyte Group									
Row	Species	Symbol	Formula	Zr content	Ca content	Member	Subgroup	Series	IMA
1	Alluaivite	Aav	$Na_{19}(Ca,Mn^{2+})_6(Ti,Nb)_3Si_{26}O_{74}Cl{\cdot}2H_2O$	§ZrTiEud	NDFTS	NMFTS	NSgFTS	NSrFTS	A
2	†Amableite-(Ce)	Ambl-Ce	$Na_{15}[(Ce_{1.5}Na_{1.5})Mn_3]Mn_2Zr_3\square Si[Si_{24}O_{69}(OH)_3](OH)_2{\cdot}H_2O$	ZrEud	CaPZrE	*T*+*M*	Oneillite	NSrITS	A
3	†Andrianovite	Adv	$Na_{12}(K,Sr,Ce)_3Ca_6Mn_3Zr_3Nb(Si_{25}O_{73})(O,H_2O,OH)_5$	ZrEud	CaRZrE	*T*+Nb	Kentbrooksite	NSrITS	A
4	Aqualite	Aq	$(H_3O)_8(Na,K,Sr)_5Ca_6Zr_3Si_{26}O_{66}(OH)_9Cl$	ZrEud	CaRZrE	*T*+*T*	Aqualite	NSrITS	A
5	Carbokentbrooksite	Cktb	$(Na,\square)_{12}(Na,Ce)_3Ca_6Mn_3Zr_3NbSi_{25}O_{73}(OH)_3(CO_3){\cdot}H_2O$	ZrEud	CaRZrE	*T*+Nb	Kentbrooksite	NSrITS	A
6	†Davinciite	Dvc	$Na_{12}K_3Ca_6Fe^{2+}{}_3Zr_3(Si_{26}O_{73}OH)Cl_2$	ZrEud	CaRZrE	*T*+*T*	Eudialyte	Davinciite	A
7	†Dualite	Dua	$Na_{30}(Ca,Na,Ce,Sr)_{12}(Na,Mn,Fe,Ti)_6Zr_3Ti_3MnSi_{51}O_{144}(OH,H_2O,Cl)_9$	‡ZrTiEud	NDFTS	NMFTS	NSgFTS	NSrFTS	A
8	Eudialyte	Eud	$Na_{15}Ca_6Fe_3Zr_3Si(Si_{25}O_{73})(O,OH,H_2O)_3(Cl,OH)_2$	ZrEud	CaRZrE	*T*+*T*	Eudialyte	Eudialyte	A
9	Feklichevite	Fek	$Na_{11}Ca_9(Fe^{3+},Fe^{2+})_2Zr_3Nb(Si_{25}O_{73})(OH,H_2O,Cl,O)_5$	ZrEud	CaRZrE	*T*+Nb	Ferrokentbrooksite	Feklichevite	A
10	†Fengchengite	Fcg	$Na_{12}\square_3Ca_6Fe_{3+3}Zr_3Si(Si_{25}O_{73})(H_2O)_3(OH)_2$	ZrEud	CaRZrE	*T*+*T*	Fengchengite	Fengchengite	A
11	Ferrokentbrooksite	Fktb	$Na_{15}Ca_6Fe^{2+}{}_3Zr_3Nb(Si_{25}O_{73})(O,OH,H_2O)_3(F,Cl)_2$	ZrEud	CaRZrE	*T*+Nb	Ferrokentbrooksite	Ferrokentbrooksite	A
12	Georgbarsanovite	Gba	$Na_{12}(Mn,Sr,REE)_3Ca6Fe^{2+}{}_3Zr_3NbSi_{25}O_{76}Cl_2{\cdot}H_2O$	ZrEud	CaRZrE	*T*+Nb	Georgbarsanovite	NSrITS	A
13	†Golyshevite	Gsv	$Na_{10}Ca_9Zr_3Fe_2SiNb(Si_3O_9)_2(Si_9O_{27})_2(OH)_3(CO_3){\cdot}H_2O$	ZrEud	CaRZrE	*T*+Nb	Ferrokentbrooksite	Feklichevite	A
14	Ikranite	Ikr	$(Na,H_3O)_{15}(Ca,Mn,REE)_6Fe^{3+}{}_2Zr_3Si_{24}O_{66}(O,OH)_6Cl{\cdot}nH_2O$	ZrEud	CaPZrE	□+□	Ikranite	NSrITS	A
15	†Ilyukhinite	Ily	$(H_3O,Na)_{14}Ca_6Mn_2Zr_3Si_{26}O_{72}(OH)_2{\cdot}3H_2O$	ZrEud	CaRZrE	*T*+*T*	Manganoeudialyte	NSrITS	A
16	†Johnsenite-(Ce)	Jsn-Ce	$Na_{12}Ce_3Ca_6Mn_3Zr_3WSi_{25}O_{73}(CO_3)(OH)_2$	ZrEud	CaRZrE	*T*+W	Manganokhomyakovite	NSrITS	A
17	Kentbrooksite	Ktb	$(Na,REE)_{15}(Ca,REE)_6Mn_3Zr_3Nb(Si_{25}O_{73})(O,OH,H_2O)_3(F,Cl)_2$	ZrEud	CaRZrE	*T*+Nb	Kentbrooksite	NSrITS	A
18	Khomyakovite	Kmy	$Na_{12}Sr_3Ca_6Fe_3Zr_3W(Si_{25}O_{73})(O,OH,H_2O)_3(Cl,OH)_2$	ZrEud	CaRZrE	*T*+W	Khomyakovite	NSrITS	A
19	Labyrinthite	Lby	$(Na,K,Sr)_{35}Ca_{12}Fe_3Zr_6TiSi_{51}O_{144}(O,OH,H_2O)_9Cl_3$	ZrEud	CaRZrE	*T*+*T*	Eudialyte	Eudialyte	A
20	†Manganoeudialyte	Meud	$Na_{14}Ca_6Mn_3Zr_3[Si_{26}O_{72}(OH)_2](H_2O,Cl,O,OH)_6$	ZrEud	CaRZrE	*T*+*T*	Manganoeudialyte	NSrITS	A
21	Manganokhomyakovite	Mkmy	$Na_{12}Sr_3Ca_6Mn_3Zr_3W(S_{125}O_{73})(O,OH,H_2O)_3(Cl,OH)_2$	ZrEud	CaRZrE	*T*+W	Manganokhomyakovite	NSrITS	A
22	†Mogovidite	Mgo	$Na_9(Ca,Na)_{12}Fe_2Zr_3Si_{25}O_{72}(CO_3)(OH)_4$	ZrEud	CaRZrE	*T*+□	Mogovidite	NSrITS	A
23	†Odikhinchaite	Odk	$Na_9Sr_3[(H_2O)_2Na]Ca_6Mn_3Zr_3NbSi(Si_{24}O_{72})O(OH)_3(CO_3){\cdot}H_2O$	ZrEud	CaRZrE	*T*+Nb	Kentbrooksite	NSrITS	A
24	Oneillite	One	$Na_{15}Ca_3Mn_3Fe_3Zr_3Nb(Si_{25}O_{73})(O,OH,H_2O)_3(OH,Cl)_2$	ZrEud	CaPZrE	*T*+*M*	Oneillite	NSrITS	A
25	Raslakite	Rsk	$Na_{15}Ca_3Fe_3(Na,Zr)_3Zr_3(Si,Nb)Si_{25}O_{73}(OH,H_2O)_3(Cl,OH)$	ZrEud	CaPZrE	*T*+*T*	Raslakite	NSrITS	A
26	Rastsvetaevite	Rvt	$Na_{27}K_8Ca_{12}Fe_3Zr_6Si_{52}O_{144}(OH,O)_6Cl_2$	ZrEud	CaRZrE	*T*+*T*	Eudialyte	Davinciite	A
27	†Selsurtite	Ssu	$(H_3O)_{12}Na_3(Ca_3Mn_3)(Na_2Fe)Zr_3\square Si[Si_{24}O_{69}(OH)_3](OH)Cl{\cdot}H_2O$	ZrEud	CaPZrE	*T*+*M*	Oneillite	NSrITS	A
28	†Sergevanite	Sgv	$Na_{15}(Ca_3Mn_3)(Na_2Fe)Zr_3Si_{26}O_{72}(OH)_3{\cdot}H_2O$	ZrEud	CaPZrE	*T*+*T*	Sergevanite	NSrITS	A
29	†Siudaite	Siu	$Na_8(Mn^{2+}{}_2Na)Ca_6Fe^{3+}{}_3Zr_3NbSi_{25}O_{74}(OH)_2Cl{\cdot}5H_2O$	ZrEud	CaRZrE	*T*+Nb	Siudaite	NSrITS	A
30	Taseqite	Tsq	$Na_{12}Sr_3Ca_6Fe_3Zr_3NbSi_{25}O_{73}(O,OH,H_2O)_3Cl_2$	ZrEud	CaRZrE	*T*+Nb	Ferrokentbrooksite	Ferrokentbrooksite	A
31	†Voronkovite	Vrk	$Na_{15}(Na,Ca,Ce)_3(Mn,Ca)_3Fe_3Zr_3Si_{26}O_{72}(OH,O)_4Cl{\cdot}H_2O$	ZrEud	CaPZrE	*T*+*T*	Voronkovite	NSrITS	A
32	Zirsilite-(Ce)	Zir-Ce	$(Na,\square)_{12}(Ce,Na)_3Ca_6Mn_3Zr_3NbSi_{25}O_{73}(OH)_3(CO_3){\cdot}H_2O$	ZrEud	CaRZrE	*T*+Nb	Kentbrooksite	NSrITS	A

A=Approved by the IMA; □=Vacancy; (†)=amableite-(Ce) (Chukanov et al., 2024), andrianovite (Khomyakov et al., 2008a), davinciite (Khomyakov et al., 2013), dualite (Khomyakov et al., 2008b), fengchengite (Shen et al., 2027), golyshevite (Chukanov et al., 2005), ilyukhinite (Chukanov et al., 2017), johnsenite-(Ce) (Grice and Gault, 2006), manganoeudialyte (Nomura et al., 2010), mogovidite (Chukanov et al., 2005), odikhinchaite (Gritsenko et al., 2020), selsurtite (Chukanov et al., 2023), sergevanite (Chukanov et al., 2020), siudaite (Chukanov et al., 2018), voronkovite (Khomyakov et al., 2009) are new eudialyte-group species approved by the IMA, later than the subcommittee report by Johnsen et al. (2003a). ZrEud=Zr eudialyte; ZrTiEud=Zirconium-tianium eudialyte. (§)=$\sum Zr \leq 0.75$ (apfu); (‡)=$0.75 < \sum Zr \leq 2.25$ (apfu). NDFTS=No division for this species; CaPZrE=Ca-poor zirconium eudialyte; CaRZrE=Ca-rich zirconium eudialyte. NMFTS=No member for this species. NSgFTS=No subgroup for this species. NSrFTS=No series for this species; NSrITS = No series in this subgroup.

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

Row	Explanations	Column Numbers
1	Major oxides from the eudialyte-group mineral (EGM) compositions (wt%)	1-43
2	Blank	44
3	Calculated H_2O (wt%) content based on the stoichiometric constraints	45
4	Blank	46
5	Recalculated cations from the EGM compositions (apfu)	47-88
6	Blank	89
7	Occupancy of Zr and Ti at the Z site	90
8	Determination of the Ca-rich and Ca-poor EGM compositions	91
9	Identification of the member (i.e., variant) of EGM compositions	92
10	Subgroup names defined by the program	93
11	Series names defined by the program	94
12	Species defined by the program	95
13	Blank	96

(apfu) = Atoms per formula unit.

Upon the successful installation of WinEudclas, the start-up screen with various pull-down menus and equivalent shortcuts appears on the screen (Figure 1a). The program enables users to enter analytical data for the eudialyte group obtained through wet-chemical methods or electron microprobe techniques. This can be accomplished by clicking the *New* icon on the toolbar, selecting *New File* from the *File* menu dropdown, or by using the *Ctrl+N* keyboard shortcut (Figure 1b). Up to 40 chemical analytes (in wt%), except for "Sample No", are used by WinEudclas in the following order:

Sample No, SiO_2, TiO_2, ZrO_2, UO_2, ThO_2, HfO_2, Al_2O_3, Fe_2O_3, Y_2O_3, La_2O_3, Ce_2O_3, Pr_2O_3, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_2O_3, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, Nb_2O_5, Ta_2O_5, P_2O_5, WO_3, SO_3, FeO, MnO, CaO, BaO, SrO, MgO, Na_2O, K_2O, F, Cl, H_2O, and CO_2.

Data from the analysis of an eudialyte-group mineral can also be input into a blank Excel file following the above order, saving it with the extension of ".xls" or ".xlsx". After this, it can be loaded into the *Data Entry Screen* of the program 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*, data can be inserted into a blank Excel file (i.e., MyEudialyte), saved using a different file name (with the extension of ".xls" or ".xlsx"), and then loaded into the *Data Entry Screen* of the program by clicking the *Open Excel File* option from the pull-down menu of *File*. Additional information about the data entry or similar topics can be accessed by pressing the F1 function key to display the WinEudclas.chm file on the screen. A representation of the *Calculation Screen* output for the classification of eudialyte-group minerals via the program is illustrated in Figure 1c.

Worked examples

Using the selected data set from literature as well as "Species.eud" file in the installation document (i.e., WinEudclas setup file), examples are presented that show how WinEudclas can be used in the determination of chemical compositions and the eudialyte-group minerals classification. The previously typed or loaded analyses are processed by clicking the *Calculate* icon (i.e., ∑) in the *Data Entry Screen* of the program, after which all input and estimation parameters are displayed in columns 1-95 of the *Calculation Screen* (see Table 3). Pressing the Ctrl+F keys or clicking the *Open File to Calculate* option from the *Calculate* menu also executes the processing of a selected data file with the extension of ".eud" which refers to the eudialyte group. By clicking the *Send results to Excel file* icon in the *Calculation Screen*, all calculations can be stored in an Excel file (Output.xlsx) and then displayed by clicking the *Open and edit Excel file* icon.

The validity of the program output has been tested with a variety of representative EGM selected from the literature (see references in Table 3). WinEudclas calculates the compositional formula for a given eudialyte-group mineral analysis on the basis of 72 oxygen atoms (apfu). Alternatively, by clicking the one of the five options [(e.g., *Si+Nb=26 (apfu)*] from the pull-down menu of *Normalization* in the *Start-up Screen* or *Data Entry Screen*, the program calculates the empirical formula and corresponding EGM species according to the selected

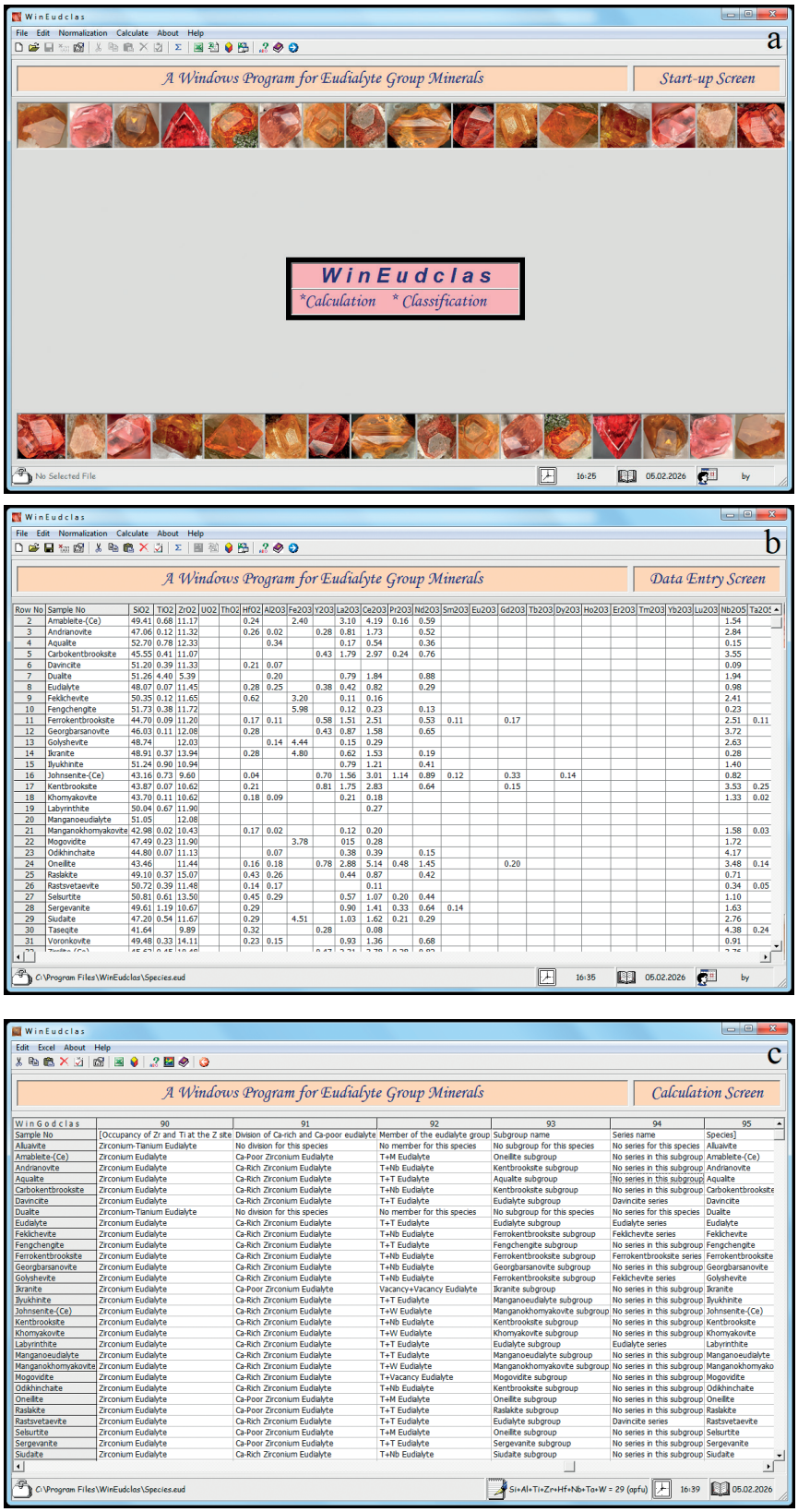

Figure 1. (a) A screenshot of the WinEudclas Start-up window with various pull-down menus and equivalent shortcuts. (b) A screenshot of the WinEudclas *Data Entry* window with a total of 40 analytes (wt%). (c) A screenshot of the WinEudclas *Calculation Screen*.

Table 3. Chemical compositions of the selected eudialyte-group minerals with calculations and classifications by WinEudclas based on the diagnostic method of Mikhailova et al. (2022).

Row		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
1	SiO_2	53.300	49.410	47.060	52.700	45.550	51.200	51.260	48.070	50.350	51.730	44.700	46.030	48.740	48.910	51.240	43.160
2	TiO_2	6.000	0.680	0.120	0.780	0.410	0.390	4.400	0.070	0.120	0.380	0.090	0.110	0.000	0.370	0.900	0.730
3	ZrO_2	0.200	11.170	11.320	12.330	11.070	11.330	5.390	11.450	11.650	11.720	11.200	12.080	12.030	13.940	10.940	9.600
4	HfO_2	0.000	0.240	0.260	0.000	0.000	0.210	0.000	0.280	0.620	0.000	0.170	0.280	0.000	0.280	0.000	0.040
5	Al_2O_3	0.000	0.000	0.020	0.340	0.000	0.070	0.200	0.250	0.000	0.000	0.110	0.000	0.140	0.000	0.000	0.000
6	Fe_2O_3	0.000	2.400	0.000	0.000	0.000	0.000	0.000	0.000	3.200	5.980	0.000	0.000	4.440	4.800	0.000	0.000
7	Y_2O_3	0.000	0.000	0.280	0.000	0.430	0.000	0.000	0.380	0.000	0.000	0.580	0.430	0.000	0.000	0.000	0.700
8	La_2O_3	0.200	3.100	0.810	0.170	1.790	0.000	0.790	0.420	0.110	0.120	1.510	0.870	0.150	0.620	0.790	1.560
9	Ce_2O_3	0.800	4.190	1.730	0.540	2.970	0.000	1.840	0.820	0.160	0.230	2.510	1.580	0.290	1.530	1.210	3.010
10	Pr_2O_3	0.000	0.160	0.000	0.000	0.240	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.140
11	Nd_2O_3	0.000	0.590	0.520	0.360	0.760	0.000	0.880	0.290	0.000	0.130	0.530	0.650	0.000	0.190	0.410	0.890
12	Sm_2O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.120
13	Gd_2O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.000	0.000	0.000	0.000	0.330
14	Dy_2O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.140
15	Nb_2O_5	3.900	1.540	2.840	0.150	3.550	0.090	1.940	0.980	2.410	0.230	2.510	3.720	2.630	0.280	1.400	0.820
16	Ta_2O_5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000
17	WO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.230
18	SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.140	0.000
19	FeO	0.000	0.000	2.430	0.560	2.220	5.330	1.040	6.130	0.280	0.690	5.080	5.570	1.190	0.380	1.150	1.610
20	MnO	3.600	8.250	3.970	0.300	5.410	0.370	2.580	0.710	0.490	0.930	3.880	2.550	0.690	3.400	3.060	5.430
21	CaO	8.600	1.890	10.260	11.140	10.610	11.020	8.030	10.890	15.550	8.960	7.990	10.730	17.240	6.290	10.630	8.980
22	BaO	0.600	0.000	0.190	2.410	0.000	0.150	0.290	0.000	0.000	0.020	0.000	0.140	0.000	0.000	0.000	0.000
23	SrO	1.000	0.000	3.110	1.750	1.420	0.980	1.370	0.000	0.280	3.530	0.450	2.240	0.000	1.610	0.000	1.600
24	MgO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	Na_2O	18.600	14.200	11.610	2.910	10.170	12.690	17.740	13.880	11.450	11.640	11.960	11.030	9.190	7.950	3.070	10.470
26	K_2O	0.200	0.410	2.050	1.950	0.510	3.530	0.080	0.290	0.000	0.520	0.440	0.350	0.460	0.440	0.320	0.250
27	F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.120	0.000	0.400	0.350	0.000	0.100	0.000	0.000
28	Cl	0.800	0.260	0.310	1.500	0.290	1.890	0.580	1.660	0.610	1.130	0.930	1.200	0.240	0.890	0.270	0.770
29	O=F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.051	0.000	0.168	0.147	0.000	0.042	0.000	0.000
30	O=Cl	0.181	0.059	0.070	0.338	0.065	0.426	0.131	0.375	0.138	0.255	0.210	0.271	0.054	0.201	0.061	0.174
31	H_2O	1.700	1.700	0.870	9.930	1.180	0.930	1.390	†0.476	1.720	2.090	0.350	0.480	1.300	7.700	10.900	0.320
32	CO_2	0.000	0.000	0.570	0.000	0.780	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.520	0.000	0.000	1.270
33	Σ (wt%)	99.319	100.131	100.260	99.482	99.295	99.754	99.669	96.195	98.932	99.775	95.402	99.972	100.196	99.437	97.369	97.996
34	Si	25.902	25.527	25.249	25.571	24.989	25.958	25.493	25.568	25.444	25.939	25.136	24.828	25.258	25.242	25.671	24.969
35	Ti	2.194	0.264	0.048	0.285	0.169	0.149	1.646	0.028	0.046	0.143	0.038	0.045	0.000	0.144	0.339	0.318
36	Zr	0.047	2.814	2.961	2.917	2.961	2.801	1.307	2.970	2.871	2.866	3.071	3.177	3.040	3.508	2.673	2.708
37	Hf	0.000	0.035	0.040	0.000	0.000	0.030	0.000	0.043	0.089	0.000	0.027	0.043	0.000	0.041	0.000	0.007
38	Al	0.000	0.000	0.013	0.194	0.000	0.042	0.117	0.157	0.000	0.000	0.073	0.000	0.086	0.000	0.000	0.000
39	Fe^{3+}	0.000	0.933	0.000	0.000	0.000	0.000	0.000	0.000	1.217	2.256	0.000	0.000	1.731	1.864	0.000	0.000
40	Y	0.000	0.000	0.080	0.000	0.126	0.000	0.000	0.108	0.000	0.000	0.174	0.123	0.000	0.000	0.000	0.216
41	La	0.036	0.591	0.160	0.030	0.362	0.000	0.145	0.082	0.021	0.022	0.313	0.173	0.029	0.118	0.146	0.333
42	Ce	0.142	0.793	0.340	0.096	0.597	0.000	0.335	0.160	0.030	0.042	0.517	0.312	0.055	0.289	0.222	0.638

Table 3. ... Continued

Row		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
43	Pr	0.000	0.030	0.000	0.000	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.240
44	Nd	0.000	0.109	0.100	0.062	0.149	0.000	0.156	0.055	0.000	0.023	0.106	0.125	0.000	0.035	0.073	0.184
45	Sm	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000	0.024
46	Gd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.063
47	Dy	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026
48	Nb	0.857	0.360	0.689	0.033	0.880	0.021	0.436	0.236	0.551	0.052	0.638	0.907	0.616	0.065	0.317	0.214
49	Ta	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000
50	W	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.784
51	S	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.429	0.000
52	Fe^{2+}	0.000	0.000	1.090	0.227	1.019	2.260	0.433	2.727	0.118	0.289	2.389	2.513	0.516	0.164	0.482	0.779
53	Mn	1.482	3.610	1.804	0.123	2.514	0.159	1.087	0.320	0.210	0.395	1.848	1.165	0.303	1.486	1.299	2.661
54	Ca	4.478	1.046	5.898	5.791	6.237	5.986	4.279	6.206	8.419	4.814	4.814	6.201	9.573	3.478	5.706	5.566
55	Ba	0.114	0.000	0.040	0.458	0.000	0.030	0.057	0.000	0.000	0.004	0.000	0.030	0.000	0.000	0.000	0.000
56	Sr	0.282	0.000	0.968	0.492	0.452	0.288	0.395	0.000	0.082	1.026	0.147	0.701	0.000	0.482	0.000	0.537
57	Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
58	Na	17.525	14.224	12.077	2.738	10.818	12.474	17.106	14.314	11.218	11.316	13.040	11.535	9.234	7.955	2.982	11.744
59	K	0.124	0.270	1.403	1.207	0.357	2.283	0.051	0.197	0.000	0.333	0.316	0.241	0.304	0.290	0.205	0.185
60	C	0.000	0.000	0.418	0.000	0.584	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.075	0.000	0.000	1.003
61	F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.192	0.000	0.711	0.597	0.000	0.163	0.000	0.000
62	Cl	0.659	0.228	0.282	1.233	0.270	1.624	0.489	1.496	0.522	0.960	0.886	1.097	0.211	0.778	0.229	0.755
63	OH	5.511	5.858	3.114	32.139	4.318	3.145	4.611	0.504	5.798	6.990	1.313	1.727	4.494	26.507	36.426	1.235
64	O	71.485	73.000	73.000	73.000	73.000	72.622	71.625	71.809	73.000	73.000	73.000	73.000	73.000	73.000	73.000	73.000
65	Σ REE (apfu)	0.178	1.522	0.600	0.189	1.156	0.000	0.636	0.297	0.050	0.088	0.989	0.610	0.084	0.442	0.441	1.508
66	OZrTiZsite	ZrTiEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrTiEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud
67	DCaRPEud	NDFTS	CaPZrE	CaRZrE	CaRZrE	CaRZrE	CaRZrE	NDFTS	CaRZrE	CaRZrE	CaRZrE	CaRZrE	CaRZrE	CaRZrE	CaPZrE	CaRZrE	CaRZrE
68	MEudG	NMFTS	TME	TNbE	TTE	TNbE	TTE	NMFTS	TTE	TNbE	TTE	TNbE	TNbE	TNbE	VVE	TTE	TWE
69	Subgroup	NSgFTS	OneSg	KtbSg	AqSg	KtbSg	EudSg	NSgFTS	EudSg	FktbSg	FcgSg	FktbSg	GbaSg	FktbSg	IkrSg	MeudSg	MkmySg
70	Series	NSrFTS	NSrITS	NSrITS	NSrITS	NSrITS	DvcSr	NSrFTS	EudSr	FekSr	NSrITS	FktbSr	NSrITS	FekSr	NSrITS	NSrITS	NSrITS
71	Species	Aav	Ambl-Ce	Adv	Aq	Cktb	Dvc	Dua	Eud	Fek	Fcg	Fktb	Gba	Gsv	Ikr	Ily	Jsn-Ce

Row		S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32
1	SiO_2	43.870	43.700	50.040	51.050	42.980	47.490	44.800	43.460	49.100	50.720	50.810	49.610	47.200	41.640	49.480	45.630
2	TiO_2	0.070	0.110	0.670	0.000	0.020	0.230	0.070	0.000	0.370	0.390	0.610	1.190	0.540	0.000	0.330	0.450
3	ZrO_2	10.620	10.620	11.900	12.080	10.430	11.900	11.130	11.440	15.070	11.480	13.500	10.670	11.670	9.890	14.110	10.480
4	HfO_2	0.210	0.180	0.000	0.000	0.170	0.000	0.000	0.160	0.430	0.140	0.450	0.290	0.290	0.320	0.230	0.000
5	Al_2O_3	0.000	0.090	0.000	0.000	0.020	0.000	0.070	0.180	0.260	0.170	0.290	0.000	0.000	0.000	0.150	0.000
6	Fe_2O_3	0.000	0.000	0.000	0.000	0.000	3.780	0.000	0.000	0.000	0.000	0.000	0.000	4.510	0.000	0.000	0.000
7	Y_2O_3	0.810	0.000	0.000	0.000	0.000	0.000	0.000	0.780	0.000	0.000	0.000	0.000	0.000	0.280	0.000	0.470
8	La_2O_3	1.750	0.210	0.000	0.000	0.120	15.000	0.380	2.880	0.440	0.000	0.570	0.900	1.030	0.000	0.930	2.310
9	Ce_2O_3	2.830	0.180	0.270	0.000	0.200	0.280	0.390	5.140	0.870	0.110	1.070	1.410	1.620	0.080	1.360	3.780
10	Pr_2O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.480	0.000	0.000	0.200	0.330	0.210	0.000	0.000	0.280
11	Nd_2O_3	0.640	0.000	0.000	0.000	0.000	0.000	0.150	1.450	0.420	0.000	0.440	0.640	0.290	0.000	0.680	0.820

Table 3. ... Continued

Row		S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32
12	Sm_2O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.140	0.000	0.000	0.000	0.000
13	Gd_2O_3	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	Dy_2O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	Nb_2O_5	3.530	1.330	0.000	0.000	1.580	1.720	4.170	3.480	0.710	0.340	1.100	1.630	2.760	4.380	0.910	3.760
16	Ta_2O_5	0.250	0.020	0.000	0.000	0.030	0.000	0.000	0.140	0.000	0.050	0.000	0.000	0.000	0.240	0.000	0.000
17	WO_3	0.000	3.800	0.000	0.000	4.480	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.290	0.770	0.000	0.000	0.000	0.000
19	FeO	2.200	4.330	2.560	0.000	2.580	1.320	0.750	3.000	5.020	2.730	1.180	1.340	0.000	3.920	3.530	1.890
20	MnO	5.190	1.630	1.000	6.960	4.210	0.680	5.490	7.700	2.010	0.490	4.730	4.150	6.450	3.020	4.650	5.670
21	CaO	8.440	10.420	10.730	11.000	10.200	18.030	12.770	2.900	5.640	10.370	6.830	7.660	9.810	8.190	3.080	10.520
22	BaO	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000
23	SrO	2.020	8.450	1.240	0.000	9.170	0.000	5.810	0.090	0.690	1.260	1.880	0.000	0.000	13.980	1.760	1.350
24	MgO	0.000	0.040	0.000	0.000	0.000	0.000	0.240	0.000	0.280	0.000	0.100	0.000	0.000	0.000	0.000	0.000
25	Na_2O	13.120	11.350	16.770	14.180	10.370	9.780	9.260	13.600	15.970	13.760	6.480	13.690	8.400	7.710	15.840	9.540
26	K_2O	0.420	0.520	1.110	0.000	0.410	0.360	0.590	0.280	0.480	6.120	0.270	1.400	0.620	0.230	0.280	0.450
27	F	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.210	0.000
28	Cl	0.470	0.670	1.700	2.320	0.840	0.520	0.690	0.760	1.340	1.330	1.010	0.230	0.540	1.910	0.440	0.320
29	O=F	0.000	0.000	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.088	0.000
30	O=Cl	0.106	0.151	0.384	0.524	0.190	0.117	0.156	0.171	0.302	0.300	0.228	0.052	0.122	0.431	0.099	0.072
31	H_2O	0.700	0.870	1.580	2.940	0.830	1.250	2.220	0.630	1.350	0.890	8.100	4.220	3.500	0.590	1.560	1.520
32	CO_2	0.000	0.000	0.000	0.000	0.000	1.420	0.900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.580
33	Σ (wt%)	97.324	98.369	99.250	100.006	98.450	113.643	99.724	98.579	100.148	100.120	99.682	100.218	99.318	95.949	99.342	99.748
34	Si	25.032	24.991	25.754	26.000	24.910	25.390	24.866	24.758	24.773	25.796	25.051	25.451	25.057	24.847	25.059	25.072
35	Ti	0.030	0.047	0.259	0.000	0.009	0.093	0.029	0.000	0.140	0.149	0.226	0.459	0.216	0.000	0.126	0.186
36	Zr	2.955	2.961	2.986	3.000	2.948	3.102	3.012	3.178	3.708	2.847	3.246	2.669	3.021	2.878	3.484	2.808
37	Hf	0.034	0.029	0.000	0.000	0.028	0.000	0.000	0.026	0.062	0.020	0.063	0.042	0.044	0.055	0.033	0.000
38	Al	0.000	0.061	0.000	0.000	0.014	0.000	0.046	0.121	0.155	0.102	0.169	0.000	0.000	0.000	0.090	0.000
39	Fe^{3+}	0.000	0.000	0.000	0.000	0.000	1.521	0.000	0.000	0.000	0.000	0.000	0.000	1.802	0.000	0.000	0.000
40	Y	0.246	0.000	0.000	0.000	0.000	0.000	0.000	0.236	0.000	0.000	0.000	0.000	0.000	0.089	0.000	0.137
41	La	0.368	0.044	0.000	0.000	0.026	2.958	0.078	0.605	0.082	0.000	0.104	0.170	0.202	0.000	0.174	0.468
42	Ce	0.591	0.038	0.051	0.000	0.042	0.055	0.079	1.072	0.161	0.020	0.193	0.265	0.315	0.017	0.252	0.760
43	Pr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.036	0.062	0.041	0.000	0.000	0.056
44	Nd	0.130	0.000	0.000	0.000	0.000	0.000	0.030	0.295	0.076	0.000	0.077	0.117	0.055	0.000	0.123	0.161
45	Sm	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000
46	Gd	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47	Dy	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
48	Nb	0.911	0.344	0.000	0.000	0.414	0.416	1.046	0.896	0.162	0.078	0.245	0.378	0.662	1.182	0.208	0.934
49	Ta	0.039	0.003	0.000	0.000	0.005	0.000	0.000	0.022	0.000	0.007	0.000	0.000	0.000	0.039	0.000	0.000
50	W	0.000	0.563	0.000	0.000	0.673	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
51	S	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.107	0.296	0.000	0.000	0.000	0.000
52	Fe^{2+}	1.050	2.071	1.102	0.000	1.251	0.590	0.348	1.429	2.118	1.161	0.487	0.575	0.000	1.956	1.495	0.869
53	Mn	2.508	0.790	0.436	3.002	2.067	0.308	2.581	3.715	0.859	0.211	1.975	1.803	2.900	1.526	1.995	2.639
54	Ca	5.160	6.385	5.917	6.003	6.334	10.328	7.594	1.770	3.049	5.651	3.608	4.211	5.580	5.236	1.671	6.193

Table 3. ... Continued

Row		S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32
55	Ba	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000
56	Sr	0.668	2.802	0.370	0.000	3.082	0.000	1.870	0.030	0.202	0.372	0.537	0.000	0.000	4.837	0.517	0.430
57	Mg	0.000	0.034	0.000	0.000	0.000	0.000	0.199	0.000	0.211	0.000	0.074	0.000	0.000	0.000	0.000	0.000
58	Na	14.515	12.585	16.734	14.002	11.653	10.138	9.965	15.021	15.623	13.569	6.194	13.617	8.646	8.920	15.554	10.163
59	K	0.306	0.379	0.729	0.000	0.303	0.246	0.418	0.203	0.309	3.971	0.170	0.916	0.420	0.175	0.181	0.315
60	C	0.000	0.000	0.000	0.000	0.000	1.036	0.682	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.435
61	F	0.000	0.000	0.179	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.336	0.000
62	Cl	0.454	0.649	1.483	2.003	0.825	0.471	0.649	0.734	1.146	1.146	0.844	0.200	0.486	1.932	0.378	0.298
63	OH	2.664	3.319	5.424	9.988	3.209	4.458	8.219	2.394	4.543	3.019	26.639	14.441	12.394	2.348	5.270	5.571
64	O	71.744	73.000	68.525	72.994	73.000	73.000	73.000	73.000	68.899	69.031	73.000	73.000	73.000	73.000	71.334	73.000
65	Σ REE (apfu)	1.118	0.082	0.051	0.000	0.068	3.013	0.187	2.110	0.318	0.020	0.410	0.639	0.612	0.017	0.549	1.446
66	OZrTiZsite	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud	ZrEud
67	DCaRPEud	CaRZrE	CaRZrE	CaRZrE	CaRZrE	CaRZrE	CaRZrE	CaRZrE	CaPZrE	CaPZrE	CaRZrE	CaPZrE	CaPZrE	CaRZrE	CaRZrE	CaPZrE	CaRZrE
68	MEudG	TNbE	TWE	TTE	TTE	TWE	TVE	TNbE	TME	TTE	TTE	TME	TTE	TNbE	TNbE	TTE	TNbE
69	Subgroup	KtbSg	KmySg	EudSg	MeudSg	MkmySg	MgoSg	KtbSg	OneSg	RskSg	EudSg	OneSg	SgvSg	SiuSg	FktbSg	VrkSg	KtbSg
70	Series	NSrITS	NSrITS	EudSr	NSrITS	NSrITS	NSrITS	NSrITS	NSrITS	NSrITS	DvcSr	NSrITS	NSrITS	NSrITS	FktbSr	NSrITS	NSrITS
71	Species	Ktb	Kmy	Lby	Meud	Mkmy	Mgo	Odk	One	Rsk	Rvt	Ssu	Sgv	Siu	Tsq	Vrk	Zir-Ce

Note: (apfu) = Atoms per formula unit. (†) = Calculated H_2O content based on the stoiciometric constraints at the X site. Samples of S1 = from Khomyakov et al. (1990), S2 = from Chukanov et al. (2024), S3 = from Khomyakov et al. (2008a), S4 = from Khomyakov et al. (2007), S5 = from Khomyakov et al. (2003), S6 = from Khomyakov et al. (2013), S7 = from Khomyakov et al. (2008b), S8 = from Borst et al. (2018), S9 = from Pekov et al. (2011), S10 = from Shen et al. (2017), S11 = from Johnsen et al. (2003b), S12 = from Khomyakov et al. (2005), S13 = from Chukanov et al. (2005), S14 = from Chukanov et al. (2003), S15 = from Chukanov et al. (2016), S16 = from Grice and Gault (2006), S17 = from Johnsen and Grice (1999), S18 = from Johnsen et al. (1999a), S19 = from Khomyakov et al. (2006a), S20 = from Nomura et al. (2010), S21 = from Johnsen et al. (1999a), S22 = from Chukanov et al. (2005), S23 = from Gritsenko et al. (2020), S24 = from Johnsen et al. (1999b), S25 = from Chukanov et al. (2003), S26 = from Khomyakov et al. (2006b), S27 = from Chukanov et al. (2023), S28 = from Chukanov et al. (2020), S29 = from Chukanov et al. (2018), S30 = from Petersen et al. (2004), S31 = from Khomyakov et al. (2009), S32 = from Khomyakov et al. (2003). OZrTiZsite = Occupancy of Zr and Ti at the Z site; DCaRPEud = Division of Ca-rich and Ca-poor eudialyte; MEudG = Member of eudialyte group (i.e., variant). ZrTiEud = Zirconium-tianium eudialyte; ZrEud = Zirconium eudialyte. NDFTS = No division for this species; CaPZrE = Ca-poor rirconium eudialyte; CaRZrE = Ca-rich zirconium eudialyte. NMFTS = No member for this species; TME = T+M Eudialyte; TNbE = T+Nb Eudialyte; TTE = T+T Eudialyte; VVE = □ + □ Eudialyte; TWE = T+W Eudialyte; TVE = T + □ Eudialyte. NSgFTS = No subgroup for this species; OneSg = Oneillite subgroup; KtbSg = Kentbrooksite subgroup; KmySg = Khomyakovite subgroup; AqSg = Aqualite subgroup; EudSg = Eudialyte subgroup; FktbSg = Ferrokentbrooksite subgroup; FcgSg = Fengchengite subgroup; GbaSg = Georgbarsanovite subgroup; IkrSg = Ikranite subgroup; MeudSg = Manganoeudialyte subgroup; MkmySg = Manganokhomyakovite subgroup; MgoSg = Mogovidite subgroup; RskSg = Raslakite subgroup; SgvSg = Sergevanite subgroup; SiuSg = Siudaite subgroup; VrkSg = Voronkovite subgroup. NSrFTS = No series for this species; NSrITS = No series in this subgroup; DvcSr = Davinciite series; Eudsr = Eudialyte series; FekSr = Feklichevite series; FktbSr = Ferrokentbrooksite series. Aav = Alluaivite; Ambl-Ce = Amableite-(Ce); Adv = Andrianovite; Aq = Aqualite; Cktb = Carbokentbrooksite; Dvc = Davinciite; Dua = Dualite; Eud =Eudialyte; Fek = Feklichevite; Fcg = Fengchengite; Fktb = Fengchengite; Gba = Georgbarsanovite; Gsv = Golyshevite; Ikr = Ikranite; Ily = Ilyukhinite; Jsn-Ce = Johnsenite-(Ce); Ktb = Kentbrooksite; Kmy = Khomyakovite; Lby = Labyrinthite; Meud = Manganoeudialyte; Mkmy = Manganokhomyakovite; Mgo = Mogovidite; Odk = Odikhinchaite; One = Oneillite; Rsk = Raslakite; Rvt = Rastsvetaevite; Ssu = Selsurtite; Sgv = Sergevanite; Siu = Siudaite; Tsq = Taseqite; Vrk = Voronkovite; Zir-Ce = Zirsilite-(Ce).

criteria. If this option is selected from the pull-down menu, WinEudclas will perform the necessary calculations but will not be able to carry out any classification processes due to the classification procedures are being only based on the [Tot29 (apfu)] normalization approach. All input and calculated parameters are presented in the *Calculation Screen* and Excel output file for the selected mineral analyses. The classification of a specific analysis by program into its appropriate member of eudialyte group (i.e., variant), subgroup and series as a distinct mineral species is conducted in accordance with the diagnostic method established by Mikhailova et al. (2022).

WinEudclas calculates and classifies the eudialyte-group mineral analyses corresponding to the analytical data in the *Calculation Screen*, as well as in the output Excel file, based on the current nomenclature scheme (e.g., see rows 1-71 in Table 3), with the determination of occupancy of Zr and Ti at the *Z* site, division of Ca-rich and Ca-poor eudialyte, member of eudialyte group (i.e., variant), subgroup name, series name and species (see rows 66-71 in Table 3). The number of ions is calculated on the basis of 72 oxygen atoms with the [Tot29 (apfu)] normalization. In a case where a chemical composition corresponds to a hitherto unknown species within the eudialyte group (i.e., a new species), WinEudclas warns the user with a "Not classified" statement in column 95

of the *Calculation Screen* for species. For example, an analysis belonging to the members of eudialyte-group with the following analytical data (see Table 1 in Bulakh and Petrov, 2004; wt%); SiO_2 48.26, ZrO_2 11.42, HfO_2 0.15, Al_2O_5 0.15, Y_2O_3 0.37, La_2O_3 0.90, Ce_2O_3 1.40, Nd_2O_3 0.45, Nb_2O_5 1.72, FeO 2.44, MnO 3.93, CaO 9.36, SrO 0.37, Na_2O 16.21, K_2O 0.26, Cl 1.13, H_2O 0.27, total 99.18. The empirical formula on the basis of 72 oxygen atoms with the [Tot29 (apfu)] normalization approach yields Si 25.475, Zr 2.939, Hf 0.081, Al 0.093, Y 0.104, Σ*REE* 0.531, Nb 0.410, Fe^{2+} 1.077, Mn 1.757, Ca 5.294, Sr 0.113, Na 16.591, K 0.175, Cl 1.011, OH 0.951 (apfu). Following Mikhailova et al. (2022), this gave: $Zr_{\Sigma 2.939}$ (apfu) > 2.25 and $Ca_{\Sigma 5.294}$ (apfu)>4.50 values, so would be defined as a zirconium and Ca-rich eudialyte, respectively. Conversely, the computed $Si_{25.475}$, $Nb_{0.410}$, and $W_{0.000}$ cations do not align with any established criteria proposed by Mikhailova et al. (2022) for EGM, including *T*+*T*, *T*+Nb, *T*+W, and *T*+□. As a result, WinEudclas is unable to classify this sample, resulting in a "Not classified" notification in column 95 of the *Calculation Screen* for users. Similarly, an analysis with the following analytical data (see Table 1 in Chakrabarty et al., 2011; wt%): SiO_2 48.89, TiO_2 0.06, ZrO_2 11.17, Al_2O_3 0.06, Ce_2O_3 2.04, Nb_2O_5 4.02, MnO 7.39, CaO 13.36, BaO 0.50, SrO 1.52, MgO 0.04, Na_2O 8.39, K_2O 0.51, Cl 0.69, total 98.69 is defined as eudialyte based on the Si=25 (apfu) normalization approach. An output from WinEudclas yields (apfu): Si 25.197, Ti 0.023, Zr 2.807, Al 0.036, Ce 0.385, Nb 0.937, Mn 3.226, Ca 7.377, Ba 0.101, Sr 0.454, Mg 0.031, Na 8.384, K 0.368, Cl 0.603, $OH_{Calculated}$ 1.397 (apfu). Taking into account the classification method of Mikhailova et al. (2022), this analysis with $Zr_{\Sigma 2.807}$ (apfu)>2.25, $Ca_{\Sigma 7.377}$ (apfu) >4.50, $25.5 \geq Si_{25.197} > 24.50$, $Nb_{0.937} > 0.5 \geq W_{0.000}$, $4.5 \geq (^{M(2)}Mn + ^{M(2)}Fe)_{3.000} > 1.5$, and $^{M(2)}Mn_{3.000} > {}^{M(2)}Fe_{0.000}$ values is defined as zirconium, Ca-rich, *T*+Nb member, and kentbrooksite subgroup, respectively. Currently, within the kentbrooksite subgroup there exist five species including kentbrooksite, carbokentbrooksite, andrianovite, odikhinchaite, and zirsiite-(Ce). Results from this analysis gives: $^{N}Na_{8.384} > 7.5$, $K_{0.368} < 1.5$, $^{N}Ca_{1.377} < 1.5$ $^{N}REE_{0.385} < 1.5$, $CO_3 \leq 0.5$ values satisfies all conditions, except $Sr_{0.454} > 1.5$, for the eudialyte group member of odikhinchaite. Consequently, the program is unable to classify this sample, resulting in a "Not classified" warning in column 95 of the *Calculation Screen*. In conclusion, according to the method of Mikhailova et al. (2022), this sample may possibly belong to a new strontium-deficient eudialyte group species, which is a derivative of the odikhinchaite mineral. All input and calculated parameters from the *Output* tab of an Excel file (i.e., Output.xlsx) are automatically transposed by the *Transpose* tab of the program. This procedure provides the user with the ability to prepare a quick table for presentation as well as publication by using the *Copy-Paste* option.

Summary and availability of the program

WinEudclas is a user-friendly program that is specially developed for personal computers running on the Windows operating system to estimate and classify the EGMs using data obtained from both electron-microprobe and wet-chemical analyses. The program processes multiple analytical data sets (up to 200) for each program execution. The current version of WinEudclas recalculates ions and classifies a total of 32 species for a given analysis using the current IMA-approved nomenclature scheme. The program generates two main windows. The first window (i.e., *Start-up/Data Entry Screen*), with several pull-down menus and equivalent shortcuts, enables users to edit a given eudialyte-group mineral analysis based on chemistry (wt%). By clicking the *Calculate* icon (i.e., ∑) in the *Data Entry Screen*, all input and estimated parameters from WinEudclas 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 95 in the *Calculation Screen* window, as well as in an Output Excel file. These columns include eudialyte group compositions (wt%), recalculated ion values (apfu), occupancy of Zr and Ti contents (apfu) at the *Z* site, division of Ca-rich and Ca-poor eudialyte, members of the eudialyte group in terms of variant, subgroup, series, and species. 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*. This file is then 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*. WinEudclas is a compiled program that consists of a self-extracting setup file containing 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 ".eud", ".xls", and ".xlsx" are installed into the personal computer (i.e., the directory of C:\Program Files\WinEudclas or C:\Program Files (x86)\WinEudclas) on Windows XP and subsequent operating systems. An installation of the program into a personal computer with a 64-bit operating system may require the "msflexgrd" adjustment (see explanations in the Supplementary Material). The self-extracting setup file (i.e., the WinEudclas setup.exe file) is approximately 11 MB and can be obtained from the journal's server as a Supplementary Material.

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