

Jasrouxite, a new Pb–Ag–As–Sb member of the lillianite homologous series from Jas Roux, Hautes-Alpes, France

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Abstract: The thallium-rich sulfosalt deposit of Jas Roux, situated in the Pelvoux Massif (Hautes-Alpes *département*, France), occurs in a Triassic sedimentary series. Jasrouxite belongs to the early lead-containing stages of the Tl–As–Sb period of mineralization. It occurs in a silicified gangue, along with smithite and late realgar. Jarouxite forms dark gray anhedral grains with metallic luster, up to several millimeters in size, as well as aggregates of grains which range to more than 10 mm in diameter. From their surface, grains of jasrouxite are embayed by a three-phase myrmekite aggregate composed of stibnite, boscardinite and smithite. The mineral is brittle, with irregular fracture; no cleavage or parting was observed. In reflected light, color is off-white. Bireflectance is weak, in off-white tones; anisotropy is distinct. Rare straight twin lamellae occur in otherwise untwinned crystals. The empirical formula, on the basis of 132 *apfu* derived from the crystal-structure determination, is $\text{Cu}_{0.79}\text{Ag}_{14.64}\text{Pb}_{4.10}\text{Tl}_{0.05}\text{As}_{15.37}\text{Sb}_{24.87}\text{S}_{72.18}$. Calculated density is 4.87 g.cm^{-3} . The simplified formula is $\text{Ag}_{16}\text{Pb}_4(\text{Sb}_{25}\text{As}_{15})_{\Sigma 40}\text{S}_{72}$; the only notable variation is the partial substitution $\text{As} \leftrightarrow \text{Sb}$. Jasrouxite is triclinic, space group *P*-1. Lattice parameters are *a* 8.2917(5) Å, *b* 19.101(1) Å, *c* 19.487(1) Å, α 89.731(1)°, β 83.446(1)°, γ 89.944(1)°, *V* 3066.1(3) Å³, *Z* = 1 for $\text{Ag}_{16}\text{Pb}_4(\text{Sb}_{24}\text{As}_{16})_{\Sigma 40}\text{S}_{72}$.

Jasrouxite is a member of the lillianite homologous series, its order number is 4 and degree of $\text{Ag} + (\text{Sb}, \text{As}) \leftrightarrow 2 \text{Pb}$ substitution is 36.5 % above the theoretical 100 % substitution expressed as $\text{PbAg}(\text{Sb}, \text{As})_3\text{S}_6$. The most important features of the crystal structure are: substantial replacement of lead in selected trigonal prismatic sites by Sb, formation of a string of large volumes for accommodation of lone electrons of Sb and As in the central portions of galena-like slabs, and high contents of Ag and (Sb,As).

Key-words: jasrouxite, new mineral, Pb–Ag–As–Sb sulfosalt, lillianite homologous series, Jas Roux, Hautes-Alpes, France.

Introduction

The thallium-rich sulfosalt deposit of Jas Roux, situated in the Pelvoux Massif of the Hautes-Alpes *département* (France), has been investigated as a Tl–As–Sb locality by the French Bureau de Recherches Géologiques et Minières only from 1969. Right from the beginning it became a source of new mineral species, starting with pierrotite (Guillemin *et al.*, 1970) and followed by routhierite, laffittite and chabournéite (Johan *et al.*, 1974; Johan *et al.*, 1981; Mantienné, 1974). A summary of sulfide mineralogy at Jas Roux, by Johan & Mantienné (2000), lists fifteen known sulfide and sulfosalt species as well as four only partially known complex sulfides. An updated summary by Favreau *et al.* (2011) lists 19 species and four insufficiently characterized ones. The present publication adds a new mineral

species to this list and mentions the presence of one more mineral, boscardinite, described recently (Orlandi *et al.*, 2012) from Tuscany, Italy.

The deposit and its mineral association

The Jas Roux deposit is situated in a Triassic sedimentary series overlying a junction of three major lithostratigraphic units forming the Pelvoux Massif in the French Western Alps (Johan & Mantienné, 2000). Blocks of Triassic sediments have a tectonic contact with the underlying crystalline basement rocks of the Sirac anticline and the overlying crystalline basement rocks of the Ecrins anticline. They are broken up into five major blocks separated by faults, named

'compartment #0' to 'compartment #4' by Mantienné (1974). Their continuation to the south is masked by colluvial sediments and moraines. The Triassic sequence starts with sandstone-arkose, continues with ~8 m dolomite unit, a ~19-m-thick limestone-and-marl unit, a massive 24-m-thick limestone unit (strongly silicified in parts), followed by argillites containing spilitite, extensive calcareous shales and sandstones, and is concluded by a black bedded limestone followed by Liassic shales [details in Mantienné & Johan (2000) and Favreau *et al.* (2011)].

The Jas Roux mineralization is best developed in the central tectonic block ('compartment #2'), in a ~4-m-thick barite-rich zone between the dolomitic unit and the limestone-and-marl unit. Lesser amounts of mineralization are present also between the latter unit and the following massive limestone. Western blocks contain dispersed mineralization; eastern ones, none. Mineralization is developed on older, NE-SW joints and it started with a pervasive silicification of the Triassic carbonates, producing jasperoid and chert. This stage was followed by formation of quartz veinlets, with fluorite and vein-like and metasomatic barite (Mantienné, 1974; Mantienné & Johan, 2000).

Both syndimentary and hydrothermal pyrite is present. Cd-bearing sphalerite is colourless to honey-yellow, with low Fe content. Mantienné & Johan (2000) and Favreau *et al.* (2011) summarize a mineral list of the deposit, based heavily on numerous preceding publications and their own electron microprobe analyses, as follows: unnamed $(\text{Pb,Tl})_9\text{Ag}(\text{Sb,As})_{13}\text{S}_{29}$, twinnite, As-bearing zinckenite, andorite, stibnite, chabournéite, parapierrrotite, pierrrotite, smithite, laffittite, routhierite, aktashite, getchellite, arsenopyrite, unnamed $\text{Tl}(\text{As,Sb})_{10}\text{S}_{16}$, unnamed $\text{Tl}(\text{Sb,As})_7\text{S}_{11}$, unnamed $\text{Ag}_2(\text{SbAs})\text{S}_4$, abundant realgar, valentinite, kermesite and clear secondary minerals, products of oxidation, which include the thallium sulphate, dorallcharite. The 'orpiment' quoted by Mantienné (1974) appears to be waka-bayashilite. There are three distinct stages of mineralization. Stage I: pyrite + sphalerite + lead sulfosalts + stibnite. Stage II is characterized by a predominance of As-Sb and Tl minerals, initially also with Pb, producing chabournéite. The late Tl-As-Hg-Ag minerals of stage III, with subordinate copper, are disseminated throughout the central block and replace the previously formed phases. Realgar concludes the mineralization process (Mantienné & Johan, 2000; Favreau *et al.*, 2011). The entire process is believed to have been caused by low-temperature hydrothermal fluids of Triassic age, similar to the present-day active geothermal systems.

At present, the locality is a well protected part of a national park and even scientific sampling is strictly regulated. Jasrouxite was collected in 2011 during a study of the deposit which was authorized by the administration of Parc National des Ecrins, and a preliminary report about this find was published in the journal of Association Française de Microminéralogie (Favreau *et al.*, 2011).

Material

By its nature, the investigated material appears to belong to the first, Pb-containing stages of mineralization, with a subdued role of thallium. Jasrouxite forms dark gray anhedral grains, up to several millimeters in size, as well as aggregates of grains which range to more than 10 mm in diameter (Fig. 1a,b). It is opaque, luster is metallic, streak gray. The mineral is brittle, with irregular fracture; cleavage and parting is missing. Density could not be measured because of paucity of available material. Calculated density is 4.87 g.cm^{-3} using the empirical chemical formula given below. Rare straight twin lamellae occur in otherwise untwinned crystals.

Homogeneous grains of jasrouxite are covered or embayed by a composite three-phase myrmekite aggregate composed of stibnite, boscardinite and smithite in intimate intergrowth (Fig. 1c–e). Remnants of jasrouxite enclosed in the base portions of myrmekite crust are rare and the myrmekitic texture is finer at the base of the aggregate. The myrmekite consists of large domains in which stibnite has a single orientation and boscardinite in principle does as well. Sinuous boscardinite grains are, however, full of parallel lamellar twins on a fine scale. The general orientation of twin aggregates changes when associated stibnite changes its orientation (Fig. 1f). Smithite has the same anisotropy colours in all parts, independent of the orientation of sister phases. In some sections, elongated myrmekitic blebs of stibnite and smithite are cemented by a network of elongated myrmekite portions of boscardinite and stibnite (Fig. 1e).

In peripheral portions of the myrmekite aggregate, realgar replaces As-bearing stibnite along median lines of its worm-like grains. Contact of affected portions with a realgar patch suggests a replacement process that postdates the development of myrmekite. Another fragment, which was situated close to jasrouxite, contains massive twinnite with loose clusters of tiny pyrite crystals and clusters of imperfect needles of As-rich zinkenite, replacing twinnite.

Chemical data

Chemical composition was determined by means of electron microprobe analysis performed on JEOL JXA-8600 electron microprobe. Twelve measurement points in two grains of jasrouxite were measured in wavelength dispersive mode with 25 kV excitation voltage, 20 nA sample current, 5 μm beam diameter and ZAF correction procedure. Analysed elements, microprobe standards and analytical wavelengths are given in Table 1. No other elements with atomic number greater than 11 were detected.

The empirical formula calculated on the basis of 132 *apfu*, derived from the crystal structure determination, is $\text{Cu}_{0.79}\text{Ag}_{14.64}\text{Pb}_{4.10}\text{Tl}_{0.05}\text{As}_{15.37}\text{Sb}_{24.87}\text{S}_{72.18}$. The simplified formula is $\text{Ag}_{16}\text{Pb}_4(\text{Sb}_{25}\text{As}_{15})_{\Sigma 40}\text{S}_{72}$.

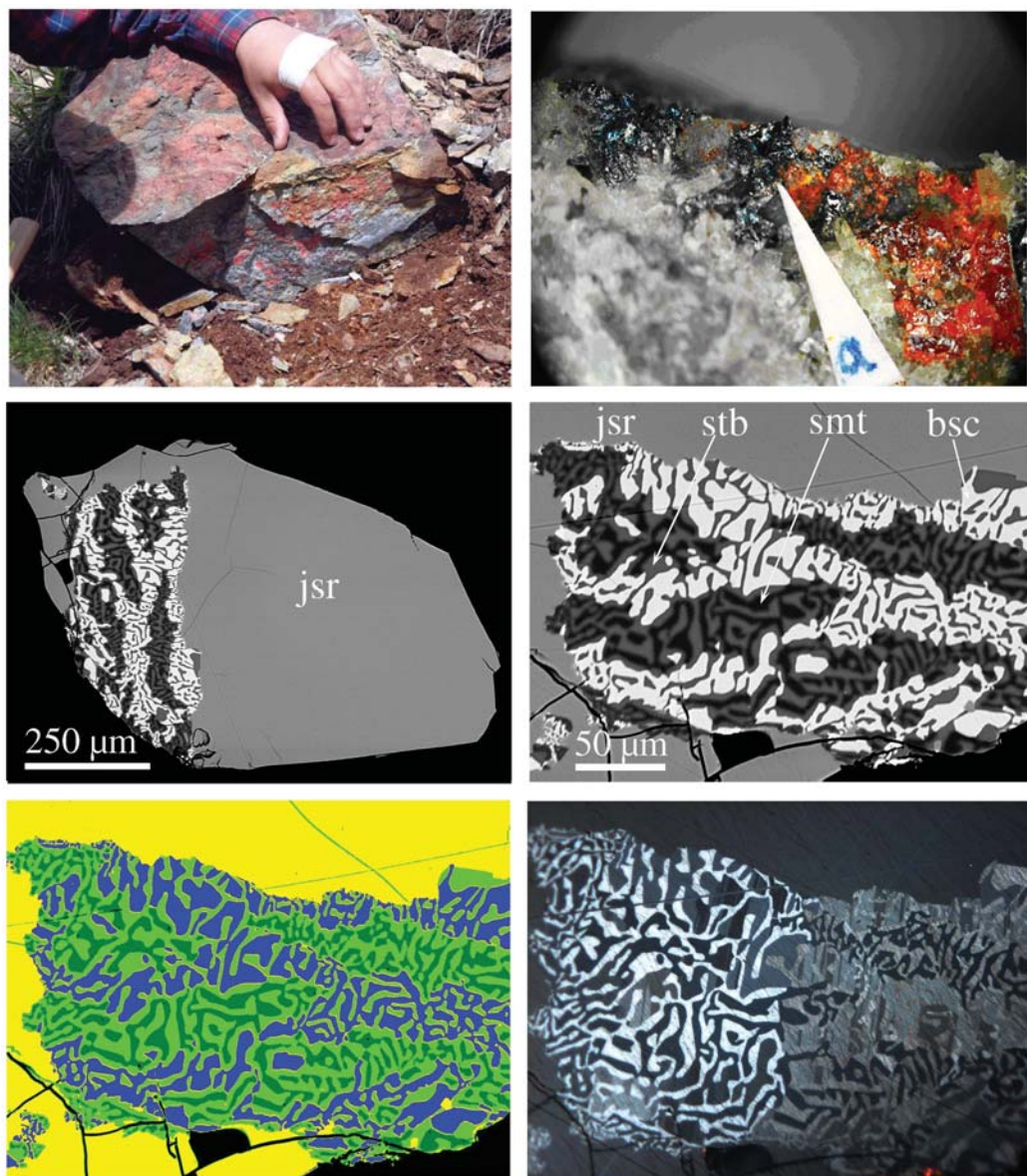


Fig. 1. (a) A stockwork of smithite (red) and jasrouxite (dark) in silicified gangue, split open at the Jas Roux deposit. (b) Macro photograph of a nest of jasrouxite (black) surrounded by smithite and realgar (red). (c-f) Embayment of myrmekite, composed of As-bearing stibnite (*stb*), smithite (*smt*) and intermediate baumhauerite–boscardinite (*bsc*), replacing large grains of jasrouxite (*jsr*). (c-e) BSE photographs, (e) with artificially colored gray scale, (f) polarized light; details in the text.

Table 1. Electron microprobe analysis results for jasrouxite.

Constituent	wt%*	Range		SD	Standards and lines
		Min	Max		
Cu	0.55	0.53	0.58	σ_{n+1} 0.01	chalcopyrite (nat.) CuK α
Ag	17.52	17.33	17.78	0.15	metal (syn.) AgL α
Pb	9.44	9.11	9.48	0.23	galena (nat.) PbM α
Tl	0.10	0.05	0.26	0.08	lorandite (nat.) TlL α
As	12.77	12.51	13.16	0.20	lorandite (nat.) AsL α
Sb	33.61	33.28	34.04	0.22	stibnite (nat.) SbL α
S	25.77	25.39	26.08	0.17	stibnite (nat.) SK α
Total	99.67	98.91	100.62	0.56	

* Mean of 12 analyses. Analytical details are given in the text.

The empirical formula (based on 132 *apfu*) is Cu_{0.79}Ag_{14.64}Pb_{4.10}Tl_{0.05}As_{15.37}Sb_{24.87}S_{72.18}.

The simplified formula is Ag₁₆Pb₄(Sb₂₅As₁₅)_{Σ40}S₇₂.

The only notable variation in Table 1 is the partial substitution $\text{As} \leftrightarrow \text{Sb}$.

Jasrouxite is a member of the lillianite homologous series, its order number and degree of $\text{Ag} + (\text{Sb}, \text{As}) \leftrightarrow 2 \text{Pb}$ substitution can be estimated from the results of electron-microprobe measurements according to the formulae derived by Makovicky & Karup-Møller (1977a). The homologue order value from chemical analysis is 3.83, close to the crystallographic value $N = 4$, whereas the substitution percentage is 136.5 %, *i.e.* 36.5 % above the theoretical composition $\text{PbAg}(\text{Sb}, \text{As})_3\text{S}_6$. The high substitution percentage is a consequence of Sb substituting in prismatic Pb sites on composition planes of the chemically twinned lillianite-like structure, which does not happen for 100 % substitution. It is the highest substitution percentage for a lillianite homologue observed to this date.

Microprobe analyses of myrmekite components show As-bearing stibnite, arsenic making less than 1/10 of the cation content of this phase, furthermore smithite, with antimony making more than 1/5 of the arsenic content, and an intermediate baumhauerite–boscardinite composition with a substantial presence of thallium, small amounts of silver and much closer contents of As and Sb than in the published analyses of these two phases. A detail description of these phases will be reported separately.

Optical properties

In reflected light, color is off-white, with weak pleochroism in air that becomes enhanced in oil. Pleochroism is weak, between off-white and whitish creamy against the associated minerals. Anisotropy is distinct in air, the rotation tints vary between pale bluish green and pale greenish blue. No internal reflections are present. The reflectance in air (Table 2, WTiC standard) shows a modest uniform decrease from 400 nm to 700 nm; the difference is about 5 %. The difference between R_{max} and R_{min} is also about 5 %.

Table 2. Reflectance values for jasrouxite in air.

λ (nm)	R_{min}	R_{max}	λ (nm)	R_{min}	R_{max}
400	31.9	37.5	560	29.7	34.7
420	31.1	36.4	580	29.1	34.3
440	31.4	35.7	589	29.1	34.1
460	30.9	35.8	600	28.9	33.9
470	30.4	35.1	620	28.8	33.5
480	30.4	35.4	640	28.6	33.3
500	30.5	35.3	650	28.2	33.1
520	30.3	35.1	660	27.8	32.5
540	29.8	34.7	680	27.6	32.3
546	29.8	34.7	700	27.2	31.9

Crystallography

Because of the scarcity of material, lattice parameters of jasrouxite were obtained from single-crystal X-ray diffraction data. In spite of near-monoclinic geometry (the β angle is the only angle substantially different from 90°), the results of structure determination confirm triclinic symmetry obtained from the unit-cell parameter estimation, and the space group $P-1$. Lattice parameters are a 8.2917(5) Å, b 19.101(1) Å, c 19.487(1) Å, α 89.731(1)°, β 83.446(1)°, γ 89.944(1)°, V 3066.1(3) Å³, $Z = 1$ for $\text{Ag}_{16}\text{Pb}_4(\text{Sb}_{25}\text{As}_{15})_{\Sigma 40}\text{S}_{72}$.

The theoretical X-ray diffraction powder pattern of jasrouxite (Table 3) was calculated with PowderCell 2.3 software (Kraus & Nolze, 1999) in Debye-Scherrer configuration employing $\text{CuK}\alpha$ radiation ($\lambda = 1.540598$ Å), a fixed slit, and no anomalous dispersion. Cell parameters, space group, atom positions, site-occupancy factors and isotropic displacement factors from the crystal-structure determination were used.

Jasrouxite is an Sb–As member of the lillianite homologous series (Makovicky & Karup-Møller, 1977a,b) with a complicated supercell based on a lillianite-like subcell. Results of a complete crystal structure determination ($R = 0.06$) based on over 14000 reflections are illustrated in Fig. 2 and are reported in detail in a parallel paper (Topa & Makovicky, *in press*). They will be used here for distinguishing the new species from other Sb-based members of the lillianite homologous series. The most important features of the structure are: (1) substantial replacement of lead in trigonal prismatic sites on the composition planes of the lillianite-like motif, with some of these sites completely replaced by Sb, (2) formation of a string of large volumes (cores of ‘lone-electron-pair micelles’) for accommodation of lone electrons of Sb and As in the central portions of galena-like slabs, around which arsenic atoms are preferably concentrated, and (3) high contents of Ag and (Sb,As).

Comparison with related As–Sb sulfosalts

The recently described menchettiite, ideally $\text{AgPb}_{2.40}\text{Mn}_{1.60}\text{Sb}_3\text{As}_2\text{S}_{12}$ (Bindi *et al.*, 2011), from the Uchucchacua polymetallic deposit in Peru, occurs also as anhedral to subhedral black grains. It is associated with orpiment, tennantite/tetrahedrite, sulfosalts and calcite. However, it is monoclinic, $P2_1/n$, with a 19.233 Å, b 12.633 Å, c 8.476 Å and β 90.08°, *i.e.*, a $1 \times 1 \times 2$ superstructure of the ideal lillianite cell. Menchettiite belongs to the cluster of moderately substituted structures in the $\text{Pb}_{3-2x}\text{Ag}_x(\text{Sb}, \text{As})_{2+x}\text{S}_6$ substitution series (the Sb subdivision of the lillianite homologous series, the line of ^{4,4}L homologues, Makovicky & Karup-Møller 1977a) and its crystal structure corresponds to the general scheme of these compounds, which comprise ramdohrite, fizelyite and uchucchacuaite (Bindi *et al.*, 2011; Yang *et al.*, 2009,

Table 3. Calculated X-ray powder diffraction data for jasrouxite.

$I_{rel.}$	$d_{calc}/\text{\AA}$	h	k	l	$I_{rel.}$	$d_{calc}/\text{\AA}$	h	k	l	$I_{rel.}$	$d_{calc}/\text{\AA}$	h	k	l
7	13.57	0	-1	1	13	3.830	0	-4	3	2	2.6232	0	-7	2
9	9.55	0	-2	0	2	3.728	1	-4	-2	7	2.5174	0	-7	-3
2	7.57	1	1	0	2	3.669	1	2	-4	4	2.5091	0	-7	3
4	7.30	1	-1	1	2	3.466	1	5	0	9	2.3876	0	-8	0
2	6.80	1	1	-1	3	3.437	1	-5	1	2	2.2609	0	-6	6
2	6.28	1	-1	2	2	3.407	0	-4	-4	2	2.1368	1	8	-3
2	6.11	0	-1	3	2	3.391	0	-4	4	2	2.1107	0	-9	-1
7	6.06	0	-3	-1	3	3.382	1	5	-1	5	2.0883	0	-7	-6
3	5.95	1	0	-2	2	3.311	1	-1	-5	3	2.0788	0	-7	6
5	5.68	1	-1	-2	2	3.309	1	-5	2	3	2.0407	0	-3	-9
2	5.45	1	-2	2	2	3.307	1	1	-5	2	2.035	0	-3	9
15	5.36	0	-2	-3	80	3.294	0	-5	-3	19	1.9646	0	-4	-9
9	5.34	0	-2	3	100	3.281	0	-5	3	17	1.9579	0	-4	9
3	5.33	0	-3	-2	2	3.228	1	-4	4	10	1.9101	0	10	0
4	5.31	0	-3	2	25	3.227	0	0	-6	4	1.878	0	-5	-9
3	5.19	1	1	3	21	3.184	0	-1	-6	6	1.8706	0	-5	9
2	5.04	1	2	-2	9	3.184	0	-6	0	3	1.7769	0	-9	-6
3	5.04	1	3	0	25	3.179	0	-1	6	2	1.7694	0	-9	6
4	4.80	1	-3	-1	2	3.061	0	-2	-6	2	1.6931	0	-7	-9
10	4.78	0	-4	0	2	3.020	0	-6	2	2	1.6787	0	11	-3
2	4.68	1	-1	-3	2	3.005	0	-5	-4	3	1.6749	0	11	3
2	4.54	0	-3	-3	2	2.9892	1	5	-3	3	1.647	0	10	-6
6	4.52	0	-3	3	2	2.9666	1	3	-5	5	1.6404	0	10	6
2	4.40	1	0	4	2	2.8762	1	6	2	2	1.6082	0	-1	-12
2	4.27	0	-4	2	33	2.8602	0	-6	-3	4	1.6069	0	-1	12
3	4.09	1	4	1	26	2.8498	0	-6	3	5	1.5919	0	-2	-12
2	3.988	1	-2	4	2	2.7037	0	-7	-1	4	1.5895	0	-2	12
33	3.847	0	-4	-3	2	2.6308	1	3	-6	2	1.4301	0	12	-6

2011; and Makovicky & Mumme, 1983; Makovicky *et al.*, 2013). Arsenic concentrates in mixed (As,Sb) polyhedra, four of which together form large lone-electron-pair micelles, typical for all these structures and for jasrouxite. However, menchettiite contains also intervening small lone-electron-pair micelles comprising only two coordination polyhedra, which are arranged *en échelon* with the large ones. In jasrouxite the smaller micelles are replaced by a set of large micelles, analogous to the previous ones. Ramdohrite, fizelyite and uchuchacuaite have fully occupied Pb sites in the composition planes of galena-like slabs of the structure. Menchettiite is the only member of the cluster in which a mixed, $\text{Pb}_{0.65}\text{Sb}_{0.35}$, site was found in this position. In contrast, jasrouxite has a heavily substituted scheme of predominantly-Pb and predominantly-Sb sites on the composition planes of the lillianite motif. On the $\text{Ag} + (\text{Sb,As}) \leftrightarrow 2 \text{Me}^{2+}$ substitution line, the fizelyite-menchettiite cluster lies at only modest, 46.5–65.5 % of Ag-(Sb,As) substitution, whereas jasrouxite lies at the highest, 136.5 % substitution, in the region in which also the Pb sites along the composition planes become object of intense substitution.

Jasrouxite is more akin to the $\sim\text{PbAgSb}_3\text{S}_6$ compositions, *i.e.*, the ~ 100 % substituted ‘andorite group’ (Moëlo, Makovicky, Karup-Møller, 1989) (Table 4): it has

a complicated supercell, and all lone-electron-pair micelles in the slabs of jasrouxite are of a large type, rich in Sb and As. In this, they are also similar to the micelles in structures of $\sim\text{PbAg}(\text{Bi,Sb})_3\text{S}_6$ compositions (Table 4). The complicated multiple periodicities along the ~ 4 Å direction of the lillianite motif that are observed for the $\sim\text{PbAgSb}_3\text{S}_6$ ‘andorite’ compositions (Table 4) are, however, replaced in jasrouxite by a doubling of the basic 4 Å period, supplemented by a superstructure built along the original ~ 13 Å direction of lillianite. Differentiation of adjacent galena-like slabs of the same thickness into two regularly alternating types with different configurations, observed in jasrouxite (Fig. 2 and Makovicky & Topa, 2013), is a rare phenomenon. It occurs in the structure of xilingolite, $\text{Pb}_3\text{Bi}_2\text{S}_6$, which is a $C2/m$ polymorph of orthorhombic $Cmcm$ lillianite (Berlepsch *et al.*, 2001). Different Pb – Bi distribution in the slabs and a consistently one-sided orientation of shorter bonds of the prismatic Pb sites are the reason for the decreased symmetry of xilingolite. In contrast, only the $\text{Sb}_3\text{-(Sb,Pb)}_5$ columns display such a consistent orientation of shorter bonds towards one set of slabs in jasrouxite.

In conclusion, on the one hand, jasrouxite widens the spectrum of structure types covered by the Pb–As–Sb sulfosalts and, on the other hand, it is a very interesting addition to the mineralogy of fairly rare epithermal

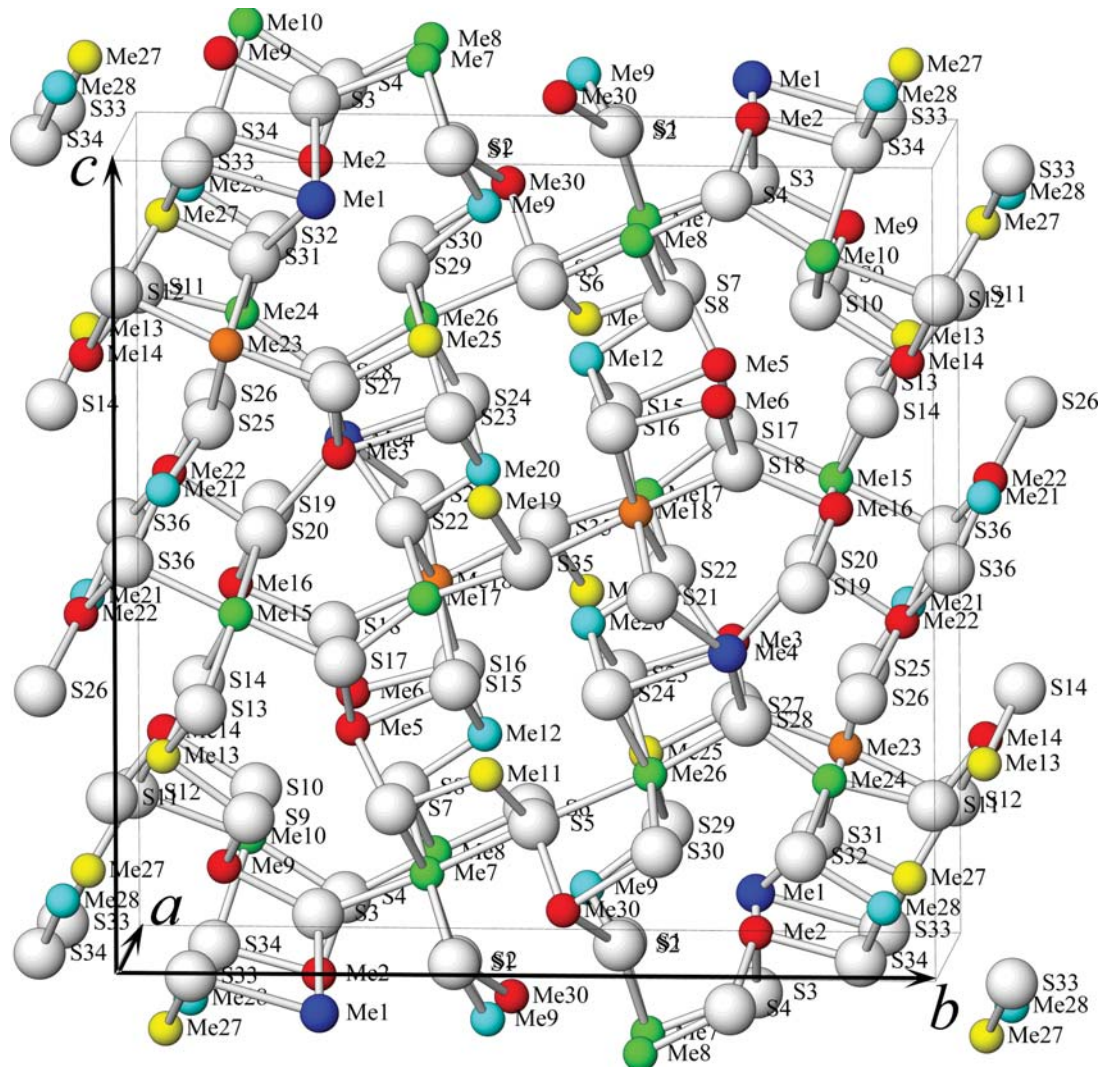


Fig. 2. Crystal structure of jaxrouxite in oblique projection upon (100). In the on-line version, in the order of decreasing size, spheres represent S, (predominantly) Pb (blue), Sb (red), mixed positions (orange Sb > As, yellow Sb ≈ As), Ag (green), and As (turquoise) (color on line). Two types of galena-like slabs alternate along the [010] direction. Note that selected lead sites on mirror planes of idealized lillianite motif are partly or fully replaced by Sb.

Pb–Tl–As–Sb mineral associations. It apparently became unstable in the presence of later solutions, giving rise to a myrmekitic reaction crust or at least replacement embayments. Comparison of the bulk chemical composition of myrmekite with that of jaxrouxite indicates absence of copper, and separation of silver, lead, Sb and As into specific phase(s) with the little changed bulk composition. Conspicuous is the addition of Tl, demonstrated by newly formed boscardinite.

Name and a deposited type material

Jaxrouxite was approved by the IMA Commission on New Minerals, Nomenclature and Classification under

No. 2012–058. The name is for locality, *Jas Roux*, La Chapelle en Valgaudemar, Parc National des Ecrins, Hautes-Alpes *département*, France, lat. 44°48'45''N, long. 6°19'18''E. Suggested pronunciation is *zhaxrouxite*.

Holotype material is deposited in the reference collection of the Department of Materials Engineering and Physics, University of Salzburg, Hellbrunnerstrasse 34/III, 5020 Salzburg, Austria, specimen number 15006. One co-type specimen is deposited in the Collection des Minéraux de Jussieu, IMPMC, Université Pierre et Marie Curie, case courrier 73, 4 place Jussieu, 75252 Paris Cedex 05, France. Another co-type specimen is deposited in the collections of the Museum of Mineralogy, Mines Paris Tech (formerly Ecole Nationale Supérieure des Mines de Paris), 60 boulevard Saint Michel, 75006 Paris, France.

Table 4. Comparative data for jasrouxite and selected homologues of lillianite.

Mineral	jasrouxite ¹	gustavite	andorite VI	roschinitite ²
Unit-cell contents ³	Ag ₁₆ Pb ₄ Sb ₂₅ As ₁₅ S ₇₂	Ag ₄ Pb ₄ Bi _{11,2} Sb _{0,8} S ₂₄	Ag ₂₄ Pb ₂₄ Sb ₇₂ S ₁₄₄	(Ag,Cu) ₁₉ Pb ₁₀ Sb ₅₁ S ₉₆
Formula based on S = 6	Ag _{1,33} Pb _{0,33} Sb ₂ As _{1,33} S ₆	AgPbBi _{2,8} Sb _{0,2} S ₆	AgPbSb ₃ S ₆	(Ag,Cu) _{1,19} Pb _{0,63} Sb _{3,19} S ₆
Substitution (%) ⁴	133	100	100	120
Crystal system	triclinic	monoclinic	orthorhombic	orthorhombic
Space group	<i>P</i> -1	<i>P</i> 2 ₁ / <i>c</i>	<i>Pn</i> 2 ₁ <i>a</i>	<i>Pmna</i>
Cell parameters				
<i>a</i>	19.487	7.056	13.005	12.946
<i>b</i>	19.101	19.691	19.155	19.048
<i>c</i>	8.292	8.222	25.622	16.932
α, β, γ (°)	89.73, 83.45, 89.94	90, 106.9, 90	90, 90, 90	90, 90, 90
Z for formula based on S = 6	12	4	24	16
Superstructure type based on parameter submultiples	<i>a</i> = 3 <i>a</i> ' <i>b</i> = <i>b</i> ' <i>c</i> = 2 <i>c</i> '	<i>a</i> = <i>a</i> ' <i>b</i> = <i>b</i> ' <i>c</i> = 2 <i>c</i> '	<i>a</i> = 2 <i>a</i> ' <i>b</i> = <i>b</i> ' <i>c</i> = 6 <i>c</i> '	<i>a</i> = 2 <i>a</i> ' <i>b</i> = <i>b</i> ' <i>c</i> = 4 <i>c</i> '
<i>a</i> ' ~ 6.5, <i>b</i> ' ~ 19.1, <i>c</i> ' ~ 4.2 and β ~ 90°				
<i>R</i> _I (%)	5.00	2.76	4.89	–
Reference ⁵	1	2	3	4, 5

¹ A transformed unit cell to allow comparison with remaining minerals; space group *P*-1, with *a* = 8.292, *b* = 19.101, *c* = 19.487 Å, α = 89.73, β = 83.45, γ = 89.94°.

² Tentative crystal structure refinement of Petrova *et al.* (1986).

³ Structural formula

⁴ Substitution in terms of Makovicky & Karup-Møller (1977b) for substitution mechanism 2Pb ↔ Ag + (Sb, Bi, As) and for general formula Ag_xPb_{3-2x}(Sb, Bi, As)_{2+x}S₆, where *x* = substitution factor and *x**100 is the substitution percentage (for *x* = 1 substitution % is 100).

⁵ [1] this study; [2] Makovicky & Topa (2011); [3] Sawada *et al.* (1987); [4] Spiridonov *et al.* (1990); [5] Petrova *et al.* (1986).

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