

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/258052495>

Arfvedsonite formed as a diabase–metapelite reaction product in contact metamorphism

Article in *Doklady Earth Sciences* · January 1991

CITATIONS

2

READS

22

2 authors:



Igor Likhanov

Sobolev Institute of Geology and Mineralogy

177 PUBLICATIONS 1,692 CITATIONS

SEE PROFILE



Reverdatto Vladimir

Sobolev Institute of Geology and Mineralogy

238 PUBLICATIONS 1,958 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



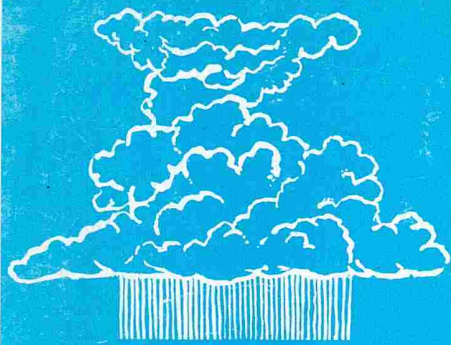
Метаморфизм сверхвысоких давлений (УНР метаморфизм) [View project](#)



Neoproterozoic evolution of Paleasian ocean at the western margin of the Siberian Craton: petrological, geochemical, isotopic, and geochronological evidences from the Yenisei Ridge [View project](#)

VOLUME 317A (NUMBER 3
MARCH-APRIL 1991)

ISSN 0012-494X



transactions

(DOKLADY)

OF THE

USSR
Academy of
Sciences

earth science
sections

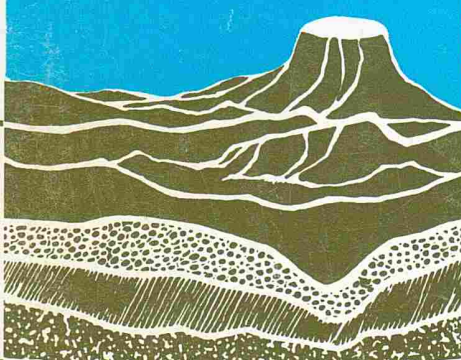
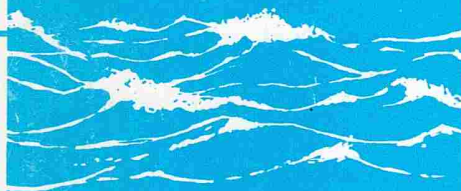
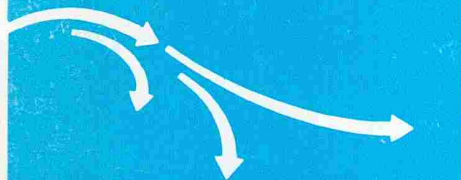


WILEY

Published by SCRIPTA TECHNICA, INC.
A Wiley Company

in cooperation with the
AMERICAN GEOLOGICAL INSTITUTE
and the
AMERICAN GEOPHYSICAL UNION

ENGLISH EDITION PUBLISHED MARCH 1993



DOK317A 03

Arfvedsonite Formed as a Diabase-Metapelite Reaction Product in Contact Metamorphism¹

I.I. Likhanov and V.V. Reverdatto

Institute of Geology and Geophysics, Siberian Department,
USSR Academy of Sciences, Novosibirsk

(Presented by Academician N.V. Sobolev, January 18, 1991)

Arfvedsonite is virtually never formed by isochemical rock metamorphism. One explanation of this is that for its formation the original rock would have to be enriched in iron, silicon and sodium, but devoid of or substantially deficient in aluminum. All known arfvedsonite finds resulted from hydrothermal and metasomatic processes in which sodium and iron were introduced. In particular, such processes could explain how arfvedsonite was formed in metamorphosed amphibole-muschketowite quartzite from the Krivoy Rog district [1], in metamorphosed ultramafic rocks from the Bazheovo pluton, Urals [2], and in gneiss from the outer-contact aureole of alkalic granite in the Keyvy district, Kola Peninsula [3]. In metamorphic iron formation from Wabush in Labrador, Canada, Klein [15] described interpenetrating grains of magnesium arfvedsonite and cummingtonite as exsolution products.

Here we shall describe our arfvedsonite find in the contact aureole of the Kharlovo gabbro intrusion, located in the northwestern Gornyy Altai foothills on the middle course of the Charysh River [4-7]. This intrusion in plan is nearly circular and has an outcrop area of about 12 km². Its contacts are discordant and steep. The Kharlovo intrusion consists essentially of banded olivine-titanomagnetite gabbro, norite and gabbro-norite, accompanied by subordinate anorthosite, gabbro-syenite and diorite. These rocks belong to the first intrusive phase. Granite, plagiogranite and granodiorite were injected in the second but are of very limited extent.

Interbedded with thin bodies of mafic extrusives and tuffs, the host rocks of the intrusion are Cambrian-Ordovician sandstones and schists. They were regionally metamorphosed under conditions of the greenschist facies. The thermal effect of intrusive gabbro on schist is expressed as hornfels.

The contact metamorphism here was studied in great detail [4, 6]. In particular, it was shown that hornfels was formed isochemically, having thereby inherited the major- and trace-element composition of the original rocks [9, 10]. As recorded from the first appearance of biotite in metapelite, the contact aureole is as wide as 1.2 km. From the host rocks toward the intrusive

¹Translated from: Arfvedsonit kak produkt reaktsionnogo vzaimodeystviya diabazov i metapelitov pri kontaktovom metamorfizme. Doklady Akademii Nauk SSSR, 1991, Vol. 317, No. 6, pp. 1461-1465.

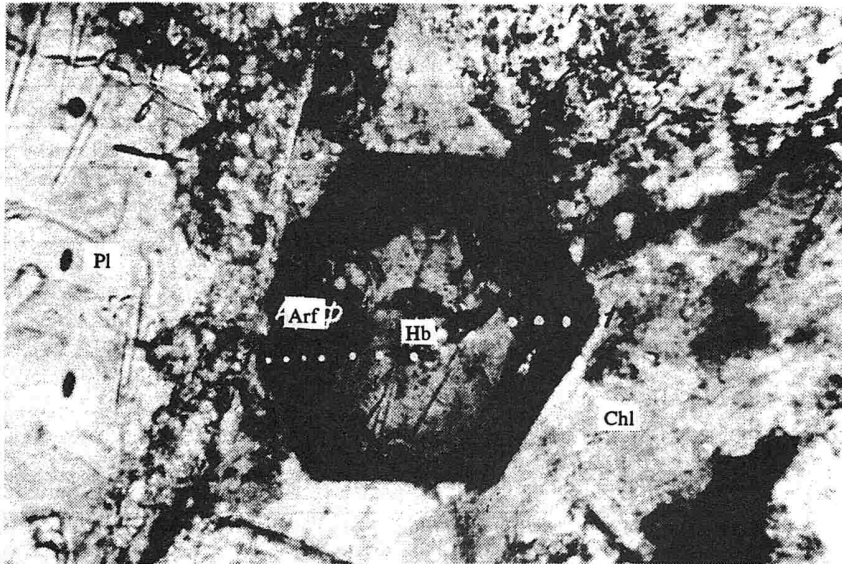


Fig. 1. Arfvedsonite rim (dark) around a hornblende grain. Sp. R-1-88, nicols ||, profile length 0.75 mm.
See Table 2 for chemical analyses of amphiboles along the profile (1 to 12).

contact, the metamorphic grade increases while the mineral parageneses change as follows² (zone name in parentheses): 1) Chl + Mu + Pl + Qu + Il + Ep + Mt ± Hem (host rock), 2) Bt + Mu + Chl + Qu + Pl + Mt ± Ep (hornfelsed biotite schists), 3) Cor + Bt + Mu + Qu + Pl + Mt (spotted cordierite hornfels), 4) Cor + Bt + Pl + Qu + And ± Mt (massive cordierite-biotite hornfels), 5) Cor + Bt + Pl + KSp + Qu ± And ± Mt (orthoclase hornfels), 6) Cor + Bt + Spl + Sil + Pl + KSp ± Mt (quartz-free segregations in orthoclase hornfels).

The rare thin sheets of mafic extrusives among the host schists consist of amygdaloidal diabase. It is a greenish-gray massive rock with round zoned inclusions, no larger than 2 to 3 mm and composed of chlorite and calcite, which forms the inner parts of the amygdules. The rock texture is poikilophitic.

This diabase consists essentially of plagioclase, chlorite, calcite and ilmenite. Its typical chemical composition is: SiO₂ 48.1 weight percent, Al₂O₃ 14.93, TiO₂ 2.5, MgO 4.49, CaO 7.66, Fe₂O₃ 7.29, FeO 3.71, MnO 0.17, K₂O 0.47, Na₂O 3.61, P₂O₅ 0.84, H₂O 0.61, ign. loss 5.52, Σ 99.9. The schist has the following composition: SiO₂ 60.32 weight percent, Al₂O₃ 19.16, TiO₂ 0.97, MgO 3.54, CaO 0.87, Fe₂O₃ 2.4, FeO 5.08, MnO 0.09, K₂O 2.87, Na₂O 3.1, P₂O₅ 0.26, H₂O 0.12, ign. loss 1.04 Σ 100.53.

We investigated a thermally metamorphosed diabase sheet in the middle of the contact aureole, i.e., in the massive cordierite-biotite hornfels zone. Its contact metamorphism produced

²Mineral symbols: Ab) albite, And) andalusite, An) anorthosite, Arf) arfvedsonite, Bt) biotite, Cc) calcite, Chl) chlorite, Cor) cordierite, Ep) epidote, Hb) hornblende, Hem) hematite, Il) ilmenite, KSp) potassic feldspar, Mt) magnetite, Mu) muscovite, Pl) plagioclase, Qu) quartz, Sil) sillimanite, Sph) sphene, Spl) spinel, Tmt) titanomagnetite.

Table 1

Chemical composition and crystallochemical coefficients
of metamafic rock minerals

Oxide	Chl	Hb(<i>n</i> =8)	Arf (<i>n</i> = 13)	Bt	Pl	Il	Sph	Tmr	Ab
SiO ₂	32,32	40,70	48,97	35,58	52,56	0	29,03	0	68,92
TiO ₂	0,03	3,23	1,77	5,44	0,08	47,68	40,21	5,81	0,01
Al ₂ O ₃	11,58	9,92	1,18	11,45	29,21	0,20	0,56	0,22	19,32
FeO	26,45	23,18	33,06	29,63	0,43	50,35	0,66	84,36	0,52
MnO	0,17	0,45	1,13	0,21	0	0	0,05	0	0,03
MgO	17,20	6,81	1,62	5,56	0,08	0,04	0,03	2,27	0
CaO	0,30	10,26	2,27	0,08	11,82	0	26,75	0	0,40
Na ₂ O	0,11	3,15	7,56	0,19	4,36	0	0,08	0	9,41
K ₂ O	0,04	0,78	1,39	8,06	0,14	0	0,04	0	0,39
Σ	88,20	98,48	98,95	96,30	98,68	98,26	97,31	92,66	99,00
Si	3,39	6,31	7,77	2,83	2,41	0	0,97	0	3,01
Al ^{IV}	0,61	1,69	0,23	1,07	1,58	0	0	0	0,99
Al ^{VI}	0,82	0,12	0	0	0	0	0	0	0
Ti	0	0,38	0,22	0,33	0	0,94	1,01	0,17	0
Fe	2,32	3,01	4,39	1,97	0,02	1,11	0	2,8	0,02
Mg	2,69	1,57	0,38	0,66	0,01	0	0	0,2	0,01
Mn	0,02	0,04	0,15	0,01	0	0	0	0	0
Ca	0,03	1,71	0,39	0,01	0,58	0	0,96	0	0,01
Na	0,02	0,95	2,33	0,03	0,39	0	0	0	0,80
K	0,01	0,17	0,28	0,82	0,01	0	0	0	0,01
Σ	9,91	15,95	16,14	7,73	5,00	2,05	2,94	3,17	4,85
Fe ³⁺		0,17	0,19					1,55	
Fe ²⁺		2,76	4,23					1,38	

Note. Analyses were done with a Camebax electron microprobe by Ye. N. Nigmatullina. The standards were garnet, orthoclase, albite, diopside, hematite and ilmenite. Crystallochemical formulas for arfvedsonite, hornblende, chlorite, biotite, plagioclase, albite, sphene, titanomagnetite and ilmenite were calculated from 23, 23, 14, 11, 8, 8, 5, 4 and 3 oxygen atoms, respectively. The total iron content of magnetite and amphiboles was recalculated to Fe³⁺ and Fe²⁺ the methods proposed by Carmichael [13] and Papike [14], respectively; *n* denotes number of analyses in the sample group used to calculate average compositions (for hornblende and arfvedsonite).

hornblende as prismatic crystals no longer than 0.5 mm. Judging by the analyses with a Camebax Microbeam electron microprobe (Table 1), this hornblende in the Leake classification [11] is close in composition to magnesium hastingsite [Si 6.25 to 6.5, Mg/(Mg + Fe²⁺) = 0.36, Fe³⁺ > Al^{VI}, (Na + K)_A 0.87, Ti 0.38]. It is accompanied by biotite (Table 1). The plagioclase becomes zoned. In grain cores, it is andesine-oligoclase [$X_{An} = Ca/(Ca + Na) \cdot 100 = 17$ to 33 percent] and, at the edges, albite [$X_{An} = 1$ to 3 percent]. The rock also contains large amounts of chlorite, calcite and ore minerals.

Arfvedsonite forms rims on hornblende grains (Fig. 1), as well as rarer needlelike segregations and prismatic crystals, ranging in length from several micrometers to fractions of a millimeter. In thin sections, it is slightly transparent and deeply colored; its pleochroism changes

Table 2

Chemical composition of hornblende and arfvedsonite along the profile shown in Fig. 1 (microprobe analyses)

Oxide	Arfvedsonite				Hornblende					Arfvedsonite		
	Pt. 1	Pt. 2	Pt. 3	P. 4	Pt. 5	Pt. 6	Pt. 7	Pt. 8	Pt. 9	Pt. 10	Pt. 11	P. 12
SiO ₂	49,21	48,95	47,09	47,23	40,84	40,38	40,51	41,26	40,26	47,22	47,79	47,49
TiO ₂	1,55	2,21	2,30	2,79	3,26	3,90	2,85	3,55	4,07	2,27	2,52	2,73
Al ₂ O ₃	0,87	1,36	1,53	1,19	10,19	9,04	10,83	10,09	11,26	1,31	1,36	1,72
FeO	31,19	33,32	31,60	33,38	23,52	24,61	22,46	22,04	22,38	31,99	33,94	32,38
MnO	0,80	0,88	1,30	1,22	0,47	0,55	0,39	0,43	0,46	1,25	1,36	1,17
MgO	3,66	1,08	1,73	0,56	5,85	5,48	7,28	7,48	6,74	1,40	0,74	1,91
CaO	0,98	2,30	2,04	1,51	10,33	10,07	10,51	9,91	9,94	1,58	2,41	2,36
Na ₂ O	8,99	7,16	8,37	8,19	3,06	3,31	3,18	3,27	3,04	8,40	7,55	7,45
K ₂ O	1,48	1,41	1,30	1,30	0,82	0,92	0,66	0,75	0,60	1,34	1,34	1,24
Σ	98,72	98,67	97,25	97,37	98,35	98,26	98,66	98,79	98,74	97,77	99,01	98,45

Note. Analyst Ye. N. Nigmatullina (our Institute); pt. denotes point in Fig. 1.

from dark blue (γ) to dark brown (α); $\alpha = 1.677$, $\gamma = 1.703$. The absorption pattern is $\alpha > \gamma$. As determined by X-ray analysis, our arfvedsonite is identical to what is given in tables [12]. In chemical composition [$\text{Si} > 7.5$, $\text{Fe}^{2+}/(\text{Fe}^{2+} + \text{Mg}) = 0.92$, $\text{Mn}_c 0.15$, $\text{Fe}^{3+}/(\text{Fe}^{3+} + \text{Al}^{\text{IV}}) > 0.5$, $(\text{Na} + \text{K})_A 1.15$, $\text{Na}_B 1.46$], this mineral can be classified as iron arfvedsonite [11]. Analyzed with a microprobe, the concentration profile across one zoned grain (Fig. 1) revealed a sharp change in chemical composition from hornblende to arfvedsonite and the absence of intermediate varieties (Table 2).

Such amphiboles could not have been formed from amygdaloidal-diabase minerals like chlorite, calcite and ilmenite. One variant of their formation in contact metamorphism could have been diffusional component exchange between diabase and the surrounding metapelite through intergranular fluid.

Considering the pattern of variation of the zoning in plagioclase and for the absence of any signs of replacement of hornblende by arfvedsonite, we used the real compositions of coexisting minerals shown in Table 1 to calculate the corresponding reactions. Done in the system $\text{SiO}_2\text{-TiO}_2\text{-Al}_2\text{O}_3\text{-FeO-MgO-MnO-CaO-Na}_2\text{O-K}_2\text{O-H}_2\text{O-CO}_2$ for hornblende (I) and in the system $\text{SiO}_2\text{-TiO}_2\text{-Al}_2\text{O}_3\text{-FeO-MgO-CaO-Na}_2\text{O-K}_2\text{O-H}_2\text{O}$ for arfvedsonite (II), such calculations gave: $\text{Chl} + 16.31\text{Cc} + 18.54\text{Il} + 16.75\text{SiO}_2 + 0.37\text{Na}_2\text{O} + 0.05\text{K}_2\text{O} = 0.23\text{Pl} + 0.7\text{Hg} + 8\text{Tmt} + 15.64\text{Sph} + 10.95\text{H}_2\text{O} + 16.31\text{CO}_2$ (I) and $\text{Chl} + 4.08\text{Pl} + 9.01\text{Tmt} + 52.86\text{SiO}_2 + 8.65\text{Na}_2\text{O} + 1.36\text{K}_2\text{O} = 5.9\text{Ab} + 6\text{Arf} + 0.6\text{Bt} + 0.3\text{H}_2\text{O}$ (II).

As follows from these equations, alkalis and silicon were added to the diabase while its volatiles were lost. Sodium and silicon concentrations in the fluid thereby increased with time, but less carbon dioxide was released during the growth of arfvedsonite.

However, there could be other variants of such reactions, particularly upon the breakdown of diabase minerals and the loss of Al_2O_3 , TiO_2 and CaO . If so, the mineral transformations in the system $\text{SiO}_2\text{-TiO}_2\text{-Al}_2\text{O}_3\text{-FeO-MgO-CaO-Na}_2\text{O-K}_2\text{O-H}_2\text{O-CO}_2$ for hornblende (III) and in the system $\text{SiO}_2\text{-TiO}_2\text{-Al}_2\text{O}_3\text{-FeO-MgO-CaO-Na}_2\text{O-H}_2\text{O}$ for arfvedsonite (IV) will be: $0.43\text{Chl} + 1.4\text{Cc} + 13\text{Il} + 0.04\text{Pl} = 5.6\text{TMt} + 0.028\text{Hb} + 1.4\text{Sph} + 0.32\text{Al}_2\text{O}_3 + 10\text{TiO}_2 + 5.12\text{H}_2\text{O} + 1.4\text{CO}_2$ (III) and $0.23\text{Chl} + 1.9\text{Pl} + 0.93\text{TMt} + 0.28\text{Il} + 2.65\text{H}_2\text{O} = 0.31\text{Arf} + 1.1\text{Bt} + 1.1\text{Al}_2\text{O}_3 + \text{CaO}$ (IV).

Reactions III and IV are very unlikely because both Al_2O_3 and TiO_2 migrate the least in the differential mobility series of components [8]; Na_2O , SiO_2 , H_2O and CO_2 are highly mobile, so their addition or loss in reactions I and II is completely possible. Note also that reaction IV must be accompanied by water absorption, which is unlikely in progressive metamorphism.

Thus, the studied amphiboles were formed as reaction products of diabase and metapelite as a result of the introduction into diabase of alkalis and silicon from the metapelite.

We thank V.S. Pavlyuchenko for the X-ray analyses.

REFERENCES

1. Shevchenko, Ye. B. Miner. sb. L'vovsk. geol. obshch., No. 13, pp. 305-312, 1959.
2. Spasskiy, A.A. Zapiski Vsesoyuzn. mineralogich. obshch., **91**, fasc. 1, pp. 112-119, 1962.
3. Ginzburg, I.V. Shchelochnyye granity Kol'skogo poluostrova (Alkalic Granites of the Kola Peninsula), USSR Acad. Sci. Press, Moscow, 1958.
4. Reverdatto, V.V. Geologiya i geofizika, No. 7, pp. 25-32, 1967.
5. Reverdatto, V.V. Ibid., No. 5, pp. 53-63, 1970.
6. Likhanov, I.I. Ibid., No. 7, pp. 46-54, 1989.
7. Likhanov, I.I. Zapiski Vsesoyuzn. mineralogich. obshch., **119**, fasc. 3, pp. 40-48, 1990.
8. Reverdatto, V.V. and V. Yu. Kolobov. Geologiya i geofizika, No. 3, pp. 3-12, 1987.
9. Reverdatto, V.V., G.N. Anoshin, V.B. Vasilenko et al. Dokl. Akad. Nauk, **243**, No. 5, pp. 1298-1301, 1978.
10. Reverdatto, V.V. et al. Contr. Miner. Petrol., **48**, pp. 287-299, 1974.
11. Mogessie, A., R. Tessardi and S.B. Veltman. Computer and Geosci., **16**, No. 4, pp. 395-410, 1990.
12. Powder Diffraction File, JCPDS, USA, 1974.
13. Carmichael, I.S.E. Contr. Miner. Petrol., **14**, No. 1, pp. 36-64, 1967.
14. Papike, J.J., K.L. Cameron and K. Baldwin. Geol. Soc. Amer. Abs. with Progr., **6**, pp. 1053-1054, 1974.
15. Klein, C., Jr. J. Petrol., No. 9, pp. 281-330, 1968.