Shallow intrusive volcanic rocks on Mt. Raduha, Savinja-Kamnik Alps, Northern Slovenia

Plitve intruzivne vukanske kamnine na Raduh, Savinjsko – Kamniške Alpe

Polona KRALJ & Bogomir CELARC
Geological Survey of Slovenia, Dimičeva 14, 1000 Ljubljana, Slovenia

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Abstract
Volcanic rocks occurring in Ladinian (?) marls, interstratified with limestone (Solčava beds), at Grohat Alpine Meadow and Lipni plaz, Mt. Raduha, are shallow intrusives bodies with porphyric structure, and basaltic andesitic, acid andesitic and dacitic composition. Abundance of major oxides and trace elements in the studied rocks is similar to those observed in the Tertiary Smrekovec volcanic rocks suggesting contemporaneous formation and close genetic relationship.

Kratka vsebina
Vulkanske kamnine v ladinjskih (?) laporjih s tankimi vložki apnencev (solčavske plasti) na planini Grohat in Lipnem plazu na Raduhu predstavljajo plitva intruzivna telesa s porfirsko strukturo in bazično andezitno, kislo andezitno in dacitno sestavo. Vsebnosti glavnih oksidov in slednih prvin v raziskanih kamninah so močno podobne tistim v tertiarnih smrekovških vulkanskih kamninah in kažejo na njihovo medsebojno časovno in genetsko povezanost.

Introduction
Marls with intercalations of thin limestone beds of Ladinian (?) age (Solčava beds) at Lipni plaz (fig. 1, loc. 1), Grohat Alpine Meadow (fig. 1, loc. 2) and Jež (fig. 1, loc. 3), north-western flanks of Mt. Raduha, locally include smaller bodies of coherent volcanics, emplaced concordantly with the sediment bedding (Plate 1 – fig. 1.2). Their thickness, however, is rather diverse – about 5 m at Grohat, and 0.5 at Lipni plaz. At Grohat, the body length amounts to about 30 m, and grades laterally into a weathered horizon.

Both, carbonate rocks and intrusive volcanic bodies have very similar dip towards the South-East (140/40). Location 1 is newly discovered, location 2 is marked only on Working map in the scale 1:25000 for Basic geological map of SFRJ, scale 1:100000, Sheet Ravne na Koroškem (Mioč & Žnidarčič 1983) as Oligocene tuffs and tuffites lying discordantly on Lower Triassic rocks. The same geological situation is presented on location 3.

East and South-East of the studied sites, in a distance less than 6 km, Tertiary Smrekovec volcanic complex occurs. It is composed of lavas and shallow intrusive bodies of andesitic and dacitic composition (Kralj, 1986), and extensive volcaniclastic deposits. Isolated outcrops of basal Tertiary conglo-
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erates overlie discordantly Upper Triassic limestone and were found on the top of Mt. Raduha. In the Durce area near by, there are tuffs and tuffites lying on Tertiary conglomerates (Celarc, current research)

Stanko Buser (personal communication) believes the presented volcanics are Ladinian sills and dykes, similar to those found in the Jezersko area (Buser & Cajhen 1977). Another possibility is, that volcanic rocks are of Tertiary age and are genetically related to Smrekovec volcanic complex. The distance is small, especially if Mt. Raduha is not thrusted. In this contribution, geochemical and petrological characteristics of shallow intrusive volcanic rocks at Grohat and Lipni plaz are presented, and the idea of their origin discussed.

Petrography and chemical composition

The samples from Mt. Grohat and Lipni plaz are very similar according to petrological characteristics, and they closely resemble the Smrekovec coherent volcanic rocks (Kralj, 1996). They are plagioclase–magnetite vitrophyres which consists of glassy groundmass, phenocrysts, microphenocrysts and microlites (Plate 1 – Fig. 3, 4). Seriate

Plate 1 – Tabla 1

1. Outcrop of shallow intrusive volcanic rock at Lipni plaz

2. The same as Fig. 1, closer view

3. Shallow intrusive volcanic rock from Grohat under plane polarised light. The texture is volcanic, with glassy groundmass and plagioclase phenocrysts of various size. Plane polarised light, magnification 23 x

4. The same as Fig. 3, crossed nicols

5, 6. Clastic character of the rock from Jež (location 3). The rock is probably a peperite. Plane polarised light, magnification 23 x
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texture is commonly observed. Phenocrysts are plagioclases, twinned and zoned, and extensively replaced by albite, less commonly to calcite and a feldspathic mineral, most probably interlayered chlorite/smectite. Glassy groundmass is devitrified and commonly replaced by authigenic albite, microcrystalline quartz and yellowish-green feldspathic minerals. Magnetite occurs as microphenocryst and some ten µm sized xenomorphic grains, dispersed throughout the rock.

The sample taken at Jež (location 3), along the road from Spodnje Sleme to the Bistra Valley, is just a fragment in a weathered rock and was not analysed chemically. The rock is probably an altered peperite (Plate 1 – Fig. 5, 6).

Chemical composition of the studied shallow volcanic rocks is shown in Table 1. At a glance, the rocks can be classified according to the silica content as andesites and dacite. Yet, a closer view to the ignition loss and high calcium and sodium content reveals the influence of rock alteration, particularly calcitisation and albitionation of the primary constituents.

Table 1: Chemical composition of shallow intrusive volcanic rocks. R1A – Lipni plaz, G2CA, G1B, Grohat.

| Oxide/Element | Unit | R 1A | G2 Ca | G 1 B |
|---------------|------|------|-------|-------|
| SiO₂ % | 51.4 | 63.7 | 59.3 |
| TiO₂ % | 0.903 | 0.802 | 0.794 |
| Al₂O₃ % | 15.3 | 16.4 | 16.1 |
| Fe₂O₃ % | 4.78 | 5.45 |
| FeO % | 3.6 |
| MnO % | 0.14 | 0.06 | 0.08 |
| MgO % | 1.79 | 2.25 | 2.03 |
| CaO % | 10.7 | 2.99 | 4.13 |
| Na₂O % | 5.43 | 4.68 | 5.12 |
| K₂O % | 0.45 | 1.47 | 1.22 |
| P₂O₅ % | 0.23 | 0.15 | 0.14 |
| CO₂ % | 6.83 | 0.66 | 2.00 |
| L.O.I. % | 7.85 | 2.25 | 3.50 |
| Li ppm | 68 | 77 | 89 |
| Be ppm | 2.1 | 1.9 | 1.0 |
| B ppm | 16 | 23 | 26 |
| Sc ppm | 12.5 | 11.8 | 12.1 |
| V ppm | 50 | 111 | 117 |
| Cr ppm | 17 | 14 | 6 |

| Co ppm | 12 | 17 | 20 |
| Ni ppm | 5 | 3 | 5 |
| Cu ppm | 4.5 | 9.1 | 8.8 |
| Zn ppm | 61.3 | 55.2 | 53.6 |
| Ga ppm | 9 | 12 | 10 |
| Ge ppm | <10 | <10 | 10 |
| As ppm | 2 | <2 | 45 |
| Se ppm | <5 | <5 | <5 |
| Br ppm | 1 | 1 | 1 |
| Rb ppm | 12 | 37 | 29 |
| Sr ppm | 435 | 441 | 514 |
| Y ppm | 43 | 31 | 29 |
| Zr ppm | 116 | 132 | 125 |
| Nb ppm | 11 | 10 | 9 |
| Mo ppm | 1 | 1 | 2 |
| Ag ppm | 0.3 | <0.2 | <0.2 |

Element | Unit | R 1A | G2 Ca | G 1 B |
|--------|------|------|-------|-------|
| Cd ppm | <0.2 | <0.2 | <0.2 |
| In ppm | <0.5 | <0.5 | <0.5 |
| Sn ppm | 4 | 4 | 4 |
| Sb ppm | 0.4 | <0.2 | 0.9 |
| Cs ppm | 5 | <5 | 8 |
| Ba ppm | 251 | 221 |
| La ppm | 23.7 | 20.7 | 20.9 |
| Ce ppm | 47.1 | 37.7 | 39.2 |
| Pr ppm | 6.7 | 4.6 | 4.8 |
| Nd ppm | 27.9 | 20.1 | 20.0 |
| Sm ppm | 5.9 | 4.4 | 4.6 |
| Eu ppm | 2.00 | 1.01 | 1.14 |
| Gd ppm | 5.5 | 3.9 | 3.8 |
| Tb ppm | 1.0 | 0.7 | 0.7 |
| Dy ppm | 6.9 | 4.9 | 4.2 |
| Ho ppm | 1.53 | 0.97 | 0.98 |
| Er ppm | 4.3 | 3.2 | 2.7 |
| Tm ppm | 0.6 | 0.5 | 0.4 |
| Yb ppm | 3.8 | 2.8 | 2.6 |
| Lu ppm | 0.55 | 0.50 | 0.40 |
| Hf ppm | 23 | 28 | 26 |
| Ta ppm | 5 | 3 | 1 |
| W ppm | 37 | 61 | 51 |
| Au ppm | <2 | <2 | 9 |
| Hg ppm | <5 | <5 | <5 |
| Tl ppm | <0.1 | 0.1 | 0.1 |
| Pb ppm | <2 | 10 | 26 |
| Bi ppm | <5 | <5 | <5 |
| Th ppm | 5.3 | 6.1 | 3.7 |
| U ppm | 2.7 | 2.8 | 1.2 |
In the silica-total alkali diagram (Le Bas et al. 1986), the studied shallow intrusive rocks fall in the fields of basaltic trachyan-
desite, andesite and dacite (fig. 2). Based on classification using immobile elements Zr/ 
TiO$_2$–SiO$_2$ (Winchester & Floyd 1979), the rocks are andesites and dacite (fig.3), 
close to Tertiary volcanic rocks from the Smrekovec, Rogaska Slatina and Rogatec 
areas. Based on the diagram of K$_2$O/SiO$_2$ 
contents after Ewart (1979), the rock samples belong to calc-alkaline basaltic an-
desites, acid andesites and dacites. 

In general, variations of trace elements 
and some of their ratios (table 2) are well in 
the variation span of orogenic anes-
dites (Gill 1981), dacites (Ewart 1979), Tertiary 
volcanic rocks from the Smrekovec, Rogaska 
Slatina and Rogatec areas (Kralj, 1996; 
this volume), and South Pannonian 
basin (Pamic & Balen 2001). One outstanding 
exception is lithium, which is much higher 
than expected for andesites and dacites, al-
though still in the variation span for dacites. 
We believe that lithium could originate from 
the action of deuteric fluids or partial incor-
poration of the enclosing marl in to magma 
during its emplacement to the host rock. 
Rubidium is relatively low with respect to 
the data for dacites (Ewart 1979), but clo-
ser to the data of Pamic & Balen (2001) 
for andesite formations in South Pannonian 
basin. Barium is low, too. Both, low rubi-
dium and barium could be related to alter-
ation of plagioclase feldspars. On the other 
hand, strontium is very high and suggests 
that it could be partially derived from an 
external source, probably carbonate.

| Table 2: Some trace element ratios for intrusive volcanic rocks from Mt. Raduha |
|-----------------|--------|--------|-------|
| Ratio           | R 1A   | G2Ca  | G1 B  |
| K/Rb            | 308    | 330    | 348   |
| Ba/La           | 7,0    | 12,1   | 10,6  |
| Zr/Nb           | 10,5   | 13,2   | 13,9  |
| La/Th           | 4,5    | 3,4    | 5,6   |
| La/Nb           | 2,15   | 2,07   | 2,32  |
| La/Yb           | 6,24   | 7,4    | 8,0   |
| Ce/Yb           | 12,3   | 13,5   | 15,1  |

Zirconium, zinc and rare earth elements (REE) with yttrium are well in the variation 
span for andesites and dacites. Chondrite
Fig. 3. Classification using immobile elements Zr/TiO$_2$ – SiO$_2$ (Winchester & Floyd 1977).
Shallow intrusive volcanic rocks from Mt. Raduha – closed diamonds; Smrekovec volcanics – open circle, squares, triangles; Rogaška Slatina – closed square; Rogatec (Tržič) – closed triangles

normalised (Nakamura 1974) REE patterns are very similar for all analysed samples of shallow intrusive volcanic rocks (fig. 4, R 1A, G1 B, and G2Ca). Light rare earth elements (LREE) are moderately enriched with respect to heavy rare earth elements (HREE). Very small negative cerium and europium anomalies can be observed. The REE plots are similar to those observed for the Smrekovec volcanics (Kralj, 1996) and acid andesite from Zagaj at Rogaška Slatina (Kralj, this volume).

Fig. 4. Chondrite normalised REE abundance for the samples from Mt. Raduha. R 1A, Lipni plaz, G1 B and G2Ca, Grohat
In the Ce – Ce/Y diagram, volcanic rocks from Mt. Raduha are well aligned in the line for the Smrekovec volcanic rocks, and are different than acid andesite from Zagaj at Rogaška Slatina and dacite from Trlično at Rogatec (fig. 5).

Abundance of compatible trace elements Cu and Ni is low with respect to the data for dacites (Ewart 1979). Copper is low in comparison with the Smrekovec volcanics, too, but very close to the abundance observed in the lava from Trlično at Rogatec. Nickel is in the same variation range as in the Smrekovec, Rogaška Slatina and Rogatec volcanic rocks.

Conclusions

Shallow intrusive volcanic rocks from NW flanks of Mt. Raduha are classified as low potassium, calc-alkaline andesites and dacite. Trace element variations are consistent with the variation span for andesites (Gill 1981) and dacites (Ewart 1979) and are comparable with those observed in the Smrekovec, Rogaška Slatina and Rogatec volcanic rocks. Magmas seem to be emplaced in Ladinian (?) slaty marls during the Smrekovec volcanic activity owing to their week mechanical resistance and probably increasing lithostatic pressure. Shallow intrusives underwent alteration. In the early stage, it was very possibly related to the activity of deuteritic fluids and is reflected in albition of plagioclases and somewhat higher sodium content than expected from the silica content. Late-stage alteration possibly involved calcitisation and the formation of clay minerals.

References

Buser, S. & Cajhen, J. 1977: Osnovna geološka karta SFRJ 1:100000, Celovec (Klagenfurt) L 33-53. – Zvezni geološki zavod, Beograd.

Ewart, A. 1979: A review of the mineralogy and chemistry of Tertiary-recent dacitic, latitic, rhyolitic, and related silic volcanic rocks. In: F. Barker (ed.), Tronhjemites, dacites, and related rocks, Developments in Petrology 6, 13-121, Elsevier, Amsterdam.

Gill, J. B. 1981: Orogenic andesites and plate tectonics. Springer-Verlag, 390 pp, Berlin.

LeBas, M. J., LeMaitre, R. W., Streckeisen, A. & Zanettin, B. 1986: A chemical classification of volcanic rocks based on total alkali-silica diagram.- J. Petrology 27, 745-750, Oxford.

Kralj, P. 1996: Lithofacies characteristics of the Smrekovec volcanoclastics, northern Slovenia.- Geologija 39, 159-191, Ljubljana.

Mioc, P. & Znidarčič, M. 1983: Osnovna geološka karta SFRJ, Ravne na Koroškem L 33-54, 1:100000. – Zvezni geološki zavod, Beograd.

Pamić, J. & Balen, D. 2001: Petrology and geochemistry of Egerian-Eggenburgian and Badenian tholeite-calc-alkaline volcanics from the South Pannonian basin (Croatia).- N.Jb. Miner. Abh. 176, 3, 237–267, Stuttgart.

Pecceirillo, A. & Taylor, S. R. 1976: Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey.- Contrib. Miner. Petrol. 58, 63-81, Berlin.

Winchester, J. A. & Floyd, P. A. 1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements.- Chem. Geol. 20, 325-343, Amsterdam.