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Petrography, age and geochemistry of the buried "Venice Granodiorite" (Northern Italy)

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Abstract

A granodiorite body was sampled in an exploratory well in the Northern Adriatic Sea, close to the Venice Lagoon. It stands 4711 m below the sea floor, directly overlain by Triassic dolostones. The drilled core represents a unique evidence of the Southalpine crystalline basement underneath the Po plain. A Llandeilian emplacement age (461–463 Ma) is inferred by U/Pb single grain conventional dating, which supports the occurrence of an Ordovician plutonic event far southwards from the sites where it is well known in the Eastern Alps. The granodiorite is undeformed, and does not display metamorphic overprints: it therefore limits the extent of the Variscan metamorphic belt to the south. Major and trace element geochemistry, together with oxygen isotopic composition, mineralogy and occurrence of abundant metasedimentary xenoliths, point to an anatectic origin of the granodiorite.

Keywords: granodiorite, U/Pb geochronology, Southalpine basement, Ordovician, anatexis, Venice.

Introduction and geological outline

In the frame of the ENI-AGIP hydrocarbon monitoring project, several boreholes were drilled in the Po Plain (AGIP Mineraria, 1977), providing data on the subsurface stratigraphy. The borehole Assunta 1, close to the Venice Lagoon (Fig. 1), deserves particular attention as it yielded a unique sampling of the buried crystalline basement. The Veneto Plain subsoil is characterised by a Pliocene homocline substratum dipping southwards; it has been considered as part of the Adriatic foreland. The granodiorite stands 4711 m below the sea floor, directly overlain by Triassic dolostones. In the Veneto Plain, only Assunta 1 reached the crystalline basement; the neighbouring wells, as deep as Assunta 1, crossed only the sedimentary cover, suggesting the existence of a "structural high" (Pieri and Groppi, 1981).

Petrography and mineral chemistry

The granodiorite (modal analysis: Qtz: 32–35%; Kfs: 17–20%; Pl: 33–37%; Bt: 14–16%) has a medium grained, isotropic, equigranular texture. Feldspars are euhedral to subhedral and are slightly sericitised; euhedral biotite is altered into chlorite + opaques at various extents. Accessory apatite and zircon are present. Metamorphic overprints are absent; only a weak deformation is recorded by subgrains in quartz. Three different kinds of enclaves occur: (i) sub-rounded mafic microgranitoid enclaves, whose mineralogy is similar to that of the host; biotite is more abundant and poikilitic K-feldspar is present; (ii) Sil–Grt bearing xenoliths, with angular shape and sharp boundaries. Skeletal sillimanite occurs, surrounding Ms+Hc+Bt+Pl±Crd aggregates. Garnet is partially replaced by Bt+Pl symplectites; (iii) Crd–Hc–Ilm bearing surmicaceous enclaves, which display sub-rounded shapes, sharp boundaries and a patchy texture where biotite-rich clots are separated by large, poikilitic Crd which includes Ilm and Hc.

Feldspar compositional ranges are those typical for granodiorites. Biotite crystals have Fe/Mg values ranging between 1.30 and 1.68; A/CNK values vary between 1.47 and 1.95. In the discriminant diagrams proposed by Abdel-Rahman (1994, not shown), biotite compositions plot in the field of peraluminous granitoids.

Geochronology

Pieri and Groppi (1981) reported a K/Ar age of 446 ± 18 Ma, but the widespread alteration of the samples casts some doubts on its reliability; moreover, feldspar and biotite alteration also prevent-

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ed Rb/Sr method to yield reliable age results (Meli and Sassi, 2000). Consequently, U/Pb single grain conventional analyses were carried out, following the procedures described by Parrish et al. (1987, and references therein). Four different zircon populations were typologically classified according to Pupin (1980): (a) clear, elongated, colourless crystals (S2, S7 and S12 subtypes); (b) slightly turbid, elongated, colourless crystals (S7 and S12 subtypes); (c) turbid, not elongated, colourless crystals (S4 and S9 subtypes); (d) rounded, turbid, metamict crystals, not classifiable typologically. Four single grain conventional U/Pb analyses were performed on crystals belonging to the non-metamict populations (Table 1 and Fig. 2). Two crystals of group ***a*** yield concordant ages of 461 ± 9 and 463 ± 7 Ma, which can be considered identical within errors. One crystal of group ***b*** gives subconcordant ages (479 ± 40, 470 ± 8, 469 ± 10 Ma for $^{207}Pb/^{206}Pb$, $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ respectively). Within the analytical error, these ages overlap the concordant data. A crystal coming from group ***c*** yields older discordant ages (1435 ± 26, 1237 ± 12, 1001 ± 16 Ma); as other data points tightly cluster, a discordia line drawn through the data set is indeed a two-point chord: therefore the upper intercept age of 1995 ± 52 Ma cannot be univocally interpreted, as it is not possible to detect whether type ***c*** crystal underwent a single- or a multi-stage history. However, its dis-

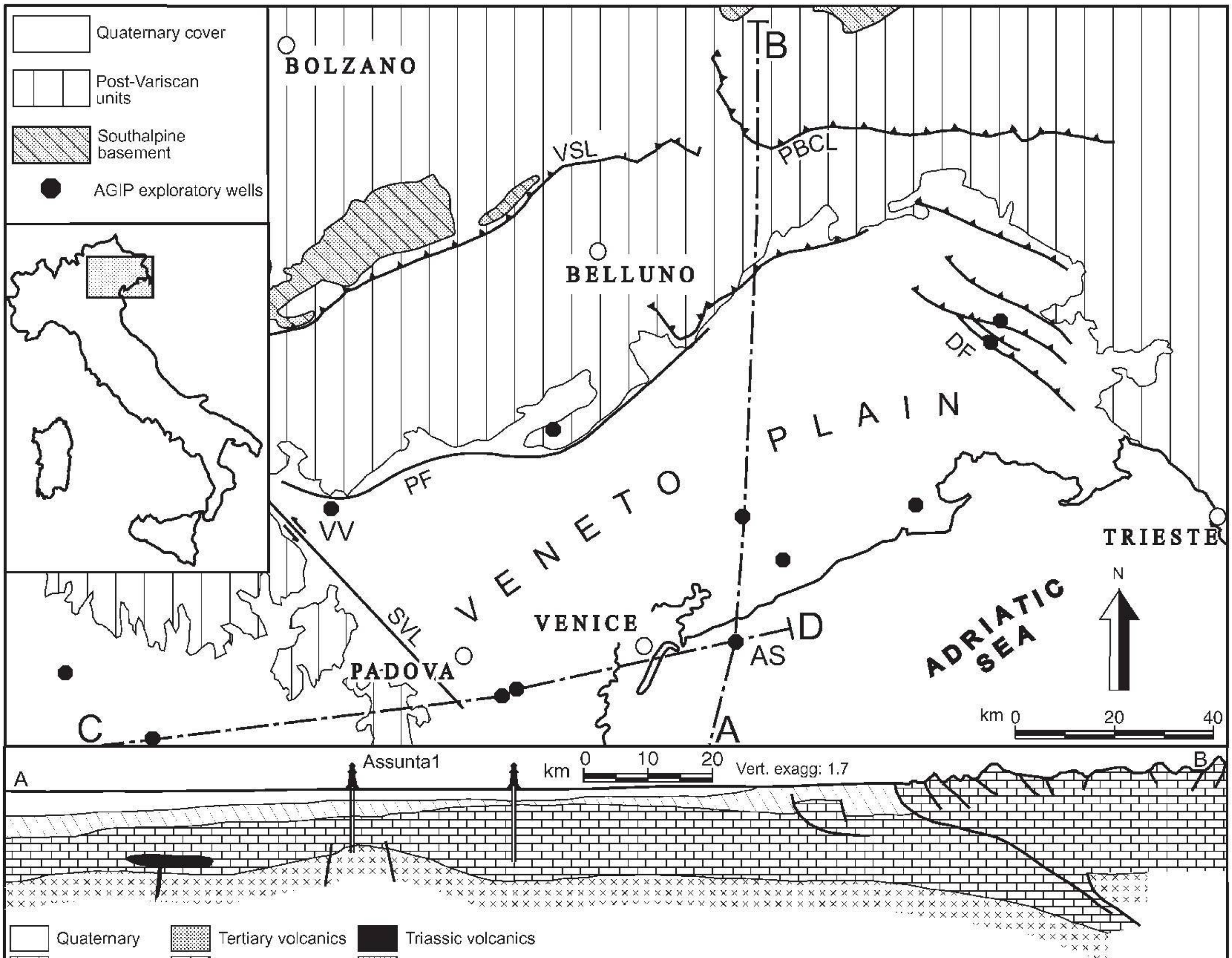

Fig. 1 Geological sketch map and selected cross sections of the Eastern Alps and the Veneto Plain (simplified after: Pieri and Groppi, 1981; Sassi and Zirpoli, 1989). VSL: Val Sugana Line; PBCL: Pineda-Branco-Circhina Line; DF: Dinaride fronts; PF: Pedealpine flexure; SVL: Schio-Vicenza Line. VV: Villaverla 1 borehole; AS: Assunta 1 borehole (location: N 45°26'18", E 12°33'19"; sea depth: 15 m; reached depth: 4747 m below the sea floor).

cordant ages testify to the contribution of at least an older crustal component to the granodiorite genesis, whose minimum age is constrained by the $^{207}Pb/^{206}Pb$ datum at 1435 ± 26 Ma.

Concordant ages obtained on clear, euhedral zircons mark the crystallisation age of the granodiorite at 461–463 Ma, thus testifying the occurrence in this site of magmatic activity during the Ordovician (Llandeilo). The Venice granodiorite is therefore coeval with the Ordovician granitoids of the "Serie dei Laghi" (Western Southalpine basement), aged 466 ± 5 Ma (Boriani et al., 1982–83), for which a calc-alkaline affinity has been established (Boriani et al., 1995); possibly, it is also coeval with the protoliths of the orthogneisses outcropping in the Monte Fioraro Magmatic Complex (Orobic Alps, Central Southalpine Basement), even if the constraints on the age of emplacement of this latter are much weaker (Colombo et al., 1994). On the other hand, the Eastern Austroalpine granitoids (Anterselva and Casies Orthogneisses), which have similar geochem-

Table 1 Zircon single grain U/Pb isotopic data.

Xtl	Pop	$^{206}Pb/^{204}Pb$ [a]	$^{207}Pb/^{235}U$ [b]	$^{206}Pb/^{238}U$ [b]	$^{207}Pb/^{206}Pb$ [b]
		isotopic ratios			
1	a	27561	0.57462 ± 2.06%	0.07413 ± 2.02%	0.05624 ± 1.7%
2	a	17983	0.57928 ± 1.66%	0.07447 ± 1.60%	0.05627 ± 1.3%
3	b	22650	0.58864 ± 2.08%	0.07547 ± 2.05%	0.05668 ± 1.8%
4	c	18610	2.37987 ± 1.66%	0.16800 ± 1.62%	0.09045 ± 1.6%

Xtl	U ppm [c]	$^{208}Pb/^{206}Pb$ [b]	Th/U today	Apparent ages $^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
1	8000	0.1071	0.33	461 ± 8	461 ± 10	462 ± 38
2	700	0.1031	0.32	464 ± 6	463 ± 8	463 ± 30
3	1500	0.1205	0.37	470 ± 8	469 ± 10	479 ± 40
4	1400	0.1059	0.30	1237 ± 12	1001 ± 16	1435 ± 26

a) measured ratios (after correction for blank and mass spectrometer fractionation); b) values corrected for common Pb, assuming that its isotopic evolution is predicted by the two stage model of Stacey and Kramers (1975); c) approximated values, as sample weighing was not possible. All errors reported are 2σ standard errors of the mean. Age calculations and error statistics were performed using a modified version of "ROCKAGE 3" from the Geological Survey of Canada and "ISOPLOT" of Ludwig (1992); decay constants are those recommended by Steiger and Jäger (1977).

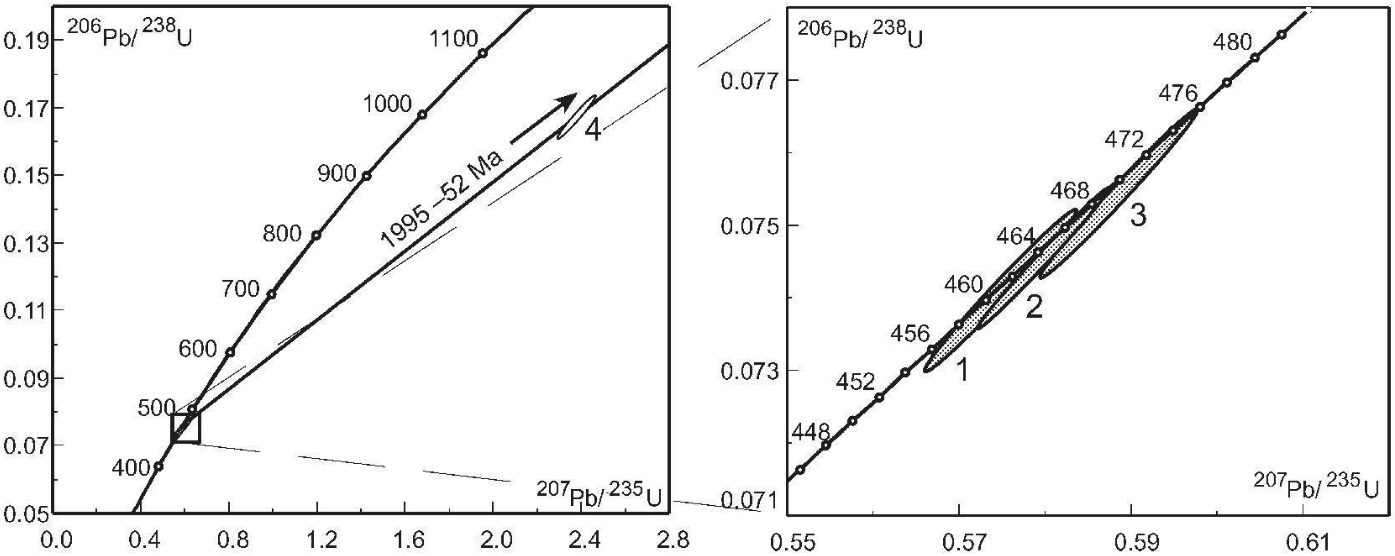

Fig. 2 Concordia diagram of the U/Pb single crystal conventional dating. Error ellipses in the left hand graph not to scale; error ellipses in the right hand graph envelope 2σ error. Numbers refer to crystal labels reported in Table 1.

ical affinities and are crust-derived (Peccerillo et al., 1979), are slightly younger (449 ± 9 Ma, Borsi et al., 1973).

Major, trace element and oxygen isotope geochemistry of the granodiorite

The host-rock major element chemistry (Table 2) confirms the modal classification; also, a peraluminous character is evident. This latter could be an artifact caused by alteration of feldspars and biotite, which modified the pristine bulk-rock chemistry; however, the modal composition of the granodiorite, together with the composition of unaltered biotite crystals, supports that alumina oversaturation is a primary feature. REE fractionation in the granodiorite is more marked for LREE than HREE (La_N/Sm_N = 2.23–2.78; Tb_N/Yb_N = 1.45–1.62); a constant negative Eu anomaly (Eu/Eu* = 0.54–0.59) is present. On the basis of bulk rock chemistry and the occurrence of xenoliths, the granodiorite can be classified as S-type (Chappell and White, 1974). In addition to chemi-

Table 2 Whole-rock chemical analyses of the granodiorite.

	Ve-1a	Ve-1b	Ve-1c	Ve-1d	Ve-2a	Ve-2b	Ve-2c	Ve-2d
SiO_2	66.0	66.1	65.7	65.3	66.4	66.1	65.8	66.1
TiO_2	0.57	0.63	0.59	0.56	0.61	0.57	0.59	0.61
Al_2O_3	15.4	15.7	15.7	15.7	15.1	15.4	15.5	15.0
Fe_2O_3(tot)	4.53	4.47	4.66	4.64	4.32	4.48	4.63	4.38
MnO	0.04	0.05	0.06	0.06	0.05	0.05	0.06	0.05
MgO	1.67	1.61	1.73	1.74	1.68	1.77	1.71	1.73
CaO	1.71	1.62	1.68	1.68	1.65	1.71	1.46	1.49
Na_2O	2.89	2.86	2.78	2.91	2.81	2.80	2.79	2.73
K_2O	4.61	4.53	4.50	4.48	4.77	4.64	4.83	4.92
P_2O_5	0.16	0.14	0.16	0.16	0.14	0.16	0.15	0.15
LOI	2.28	2.25	2.40	2.48	2.73	2.66	2.30	2.49
Total	99.85	99.91	99.86	99.68	100.30	100.36	99.80	99.64
Rb	149	155	147	115	188	171	139	129
Sr	123	123	116	96	138	124	107	105
Ba	377	373	364	310	352	454	381	402
Sc	21.4	24.3	19.1	18.0	22.9	18.6	17.1	18.2
V	45.5	45.3	47.9	47.4	44.6	45.1	47.0	44.9
Cr	55.6	76.0	70.8	72.9	54.6	65.8	50.6	51.4
Co	9.03	9.03	10.32	8.94	8.12	8.58	8.13	7.96
Ni	29.3	42.2	40.8	40.4	29.2	36.9	25.5	25.5
Ga	13.7	14.2	13.6	14.5	13.5	12.3	13.4	12.9
Y	20.8	18.3	20.5	15.3	16.1	23.8	17.6	17.0
Nb	9.55	9.50	9.99	9.86	9.31	9.46	9.85	9.39
Ta	0.99	1.01	1.04	0.97	1.12	1.05	1.17	1.07
Zr	171	167	166	173	160	164	170	167
Hf	4.07	3.77	3.91	4.05	3.75	3.94	3.97	4.02
U	2.88	2.75	2.98	2.46	2.32	3.06	2.48	2.43
Th	9.92	9.32	9.92	8.58	8.53	9.93	8.28	8.44
La	22.8	20.3	23.0	16.6	16.1	25.2	18.2	17.6
Ce	55.6	51.9	61.1	50.1	41.2	58.2	49.7	49.3
Pr	6.39	5.86	6.53	5.05	5.00	6.84	5.26	5.21
Nd	24.9	23.3	25.5	19.8	20.0	26.4	20.7	20.8
Sm	5.54	5.02	5.70	4.51	4.50	5.65	4.60	4.72
Eu	0.92	0.89	0.92	0.77	0.77	0.97	0.80	0.77
Gd	4.70	4.26	4.76	3.86	3.82	4.96	3.98	3.98
Tb	0.73	0.66	0.74	0.61	0.63	0.79	0.64	0.64
Dy	4.02	3.76	4.06	3.34	3.48	4.31	3.46	3.62
Ho	0.83	0.77	0.85	0.70	0.72	0.90	0.75	0.73
Er	2.30	2.04	2.19	1.87	1.97	2.47	2.02	1.96
Tm	0.35	0.34	0.37	0.31	0.31	0.38	0.33	0.33
Yb	2.09	1.93	2.04	1.87	1.86	2.21	1.89	1.92
Lu	0.32	0.29	0.31	0.26	0.28	0.34	0.28	0.28

Total iron as Fe_2O_3. Major and trace element concentrations are expressed in wt% and ppm, respectively.

cal data, also whole-rock and quartz oxygen isotope compositions were determined. The $\delta^{18}O$ $_{(V\text{-}SMOW)}$ values are +12.8 and +12.9 respectively. As quartz is unaltered, the measured $\delta^{18}O$ is expected to reflect its pristine value; recalculating the bulk rock $\delta^{18}O$ (the fractionation factors at temperaures between 750 and 850 °C and the granodiorite mode were employed), we obtain values comprised between +11.9 and +12.4, close to the measured ratio. These high $\delta^{18}O$ values further confirm the anatectic nature of the granodiorite: granitic rocks with $\delta^{18}O$ higher than 10‰ require derivation from some kind of $\delta^{18}O$-enriched metasedimentary source (Taylor, 1978).

Concluding remarks

1) Assunta 1 borehole, close to the Venice Lagoon, sampled the Southalpine crystalline basement below the Po plain, at about –4700 m. The recovered granodiorite specimens contain metamorphic xenoliths and minor igneous enclaves.

2) The nonconformity recorded in the stratigraphic sequence testifies that the granodiorite was exposed to the surface during Triassic, and that a long-lived sedimentary hiatus and/or erosional truncation occurred.

3) Concordant U/Pb ages on single zircons of 461 and 463 Ma (Middle Ordovician) supply a further evidence of the Ordovician igneous event in the Eastern Alps, which could be also related to the contemporary magmatism recorded in the westernmost part of the Southalpine basement. Inheritance of Middle Proterozoic crustal components is also suggested.

4) The mineralogical, chemical, and isotopic features, together with the occurrence of several metasedimentary xenoliths, point to an S-type signature of the granodiorite, which crystallised from a silicic, peraluminous melt of anatectic origin.

5) The granodiorite did not undergo post-emplacement metamorphic overprints, and is substantially undeformed. It therefore constrains southwards the extent of the Variscan metamorphic belt, being possibly involved into this orogeny only at very shallow levels.

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