Open Journal of Geology, 2015, 5, 1-12
Published Online January 2015 in SciRes. http://www.scirp.org/journal/ojg
http://dx.doi.org/10.4236/ojg.2015.51001

Pb Isotopes Data from the Campanian Volcanic Province: A Model to Generate These Distinctive Pb Isotopic Variations

Angelo Paone[1,2]

[1]United States Geological Survay, Reston, USA
[2]Dipartimento di Scienze della Terra, Università degli Studi di Napoli "Federico II", Naples, Italy
Email: angelo.paone1@gmail.com

Received 20 December 2014; accepted 11 January 2015; published 20 January 2015

Abstract

A broad set of samples from the CVP has been analyzing Pb isotopes. Campanian Volcanic Province (CVP) has been produced by various ranges of mixing between three components: 1) MORB, 2) Hercynian basement and 3) upper crust. Anyhow, the upper crust that has modified the Pb isotopic composition also shows trends towards an Achaean upper crust. This is consistent for all Mediterranean area. This is not in contrast with the past plate tectonic reconstruction. Also the surface sediments (GLOSS) may have been a mixing between the Achaean upper crust and a Hercynian component with an implication worldwide due to the rock cycle processes.

Keywords

Pb Isotopes, Campanian Volcanic Province, Hercynian, Sediments, MORB

1. Introduction

The Campanian Volcanic Province (**Figure 1**) is made of the following volcanic area: Somma-Vesuvius volcano [1], Campi Flegrei Volcanic District [2] [3], Roccamonfina volcano [3] and the Island of Ponza and Ventotene [4]. A tectonic scenario has been envisaged on the basis of geophysical, petrologic and geochemical data, where the magma is stored in the deep and hot intrusion zone [4]-[6]. The magmas erupted have a sediments signature due to the adjacent Adria slab subducting [4] [7]. Tomographic results confirm this scenario ([8], references therein). In this report, I would like to unravel the features of the Pb isotopes data from the Campanian Volcanic Province [9]-[11]. Moreover, a model is built to explain these typical Pb isotopes signatures.

How to cite this paper: Paone, A. (2015) Pb Isotopes Data from the Campanian Volcanic Province: A Model to Generate These Distinctive Pb Isotopic Variations. *Open Journal of Geology*, **5**, 1-12. http://dx.doi.org/10.4236/ojg.2015.51001

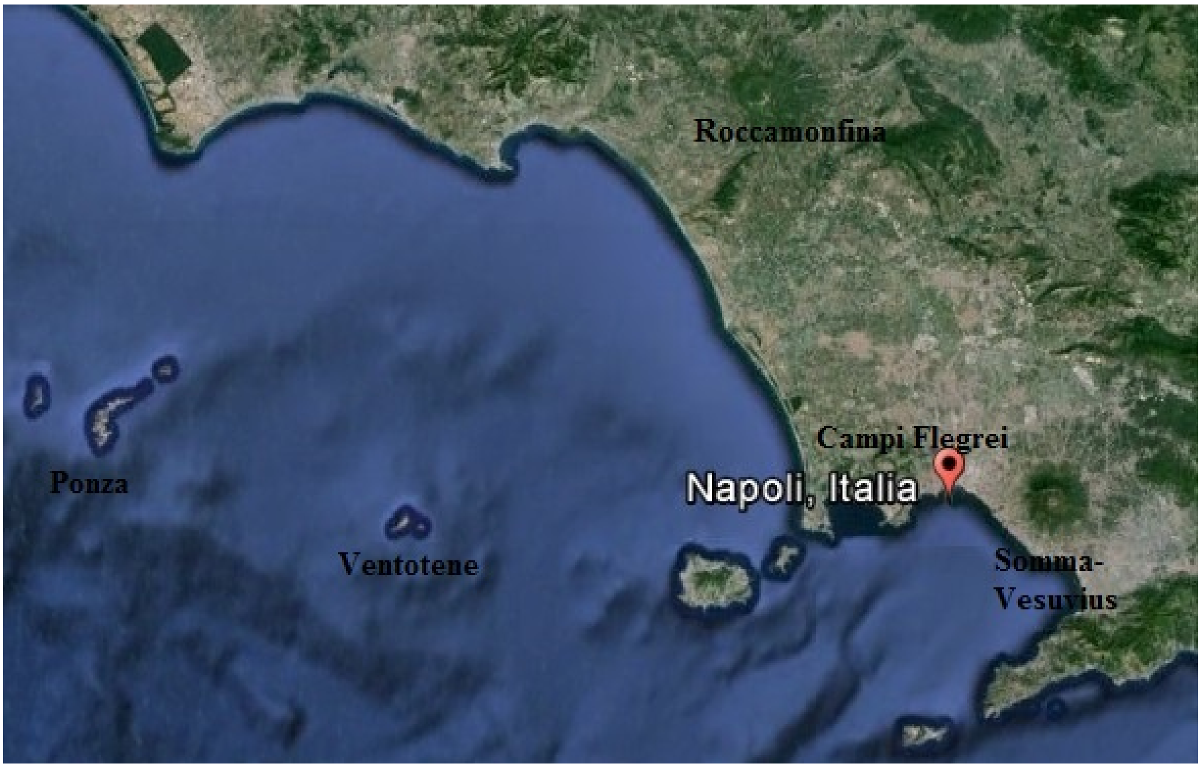

Figure 1. Aerial photograph of the main volcanic area of the Campanian Volcanic Province.

2. A Geochemical Overview to Summarize the Magmatic Origin and Crustal Effects in Campanian Volcanic Province

The Campanian Volcanic Province is part of the classic western potassic volcanic province of the Italian Peninsula. The Campanian volcanic products show the effects of shallow assimilation and fractional crystallization, and the contribution of regional crustal sources (e.g., Hercynian basement-Calabrian crust). The Roccamonfina, Campi Flegrei, and Ventotene volcanic rocks are characterised by wide isotopic and geochemical variations. Such variations appear to reflect both AFC processes and chemical heterogeneity in the upper mantle that may be linked to subduction processes. Mixing curves (Th/Ce-, Ba/K- and Eu/Eu*-^{143}Nd/^{144}Nd) linking sediments and mantle end-members account for the variations in the Campanian Province volcanic rocks with a sediment contribution of 2% - 10%. The upper mantle sources for the low- and high-K rocks at Roccamonfina have been constrained on the basis of a multi-element normalized diagram. The two sources require different amounts of sediment in the mantle wedge (LK~2% versus HK~10%) and a fluid component probably from altered ocean crust to explain the fluid mobile elements. Low-K Roccamonfina rocks are geochemically similar to those from Campi Flegrei, Ventotene, and Somma-Vesuvius, suggesting a similar proportion of sediment in their upper mantle source regions [3].

3. Sampling and Analytical Techniques

A representative suite of 300 volcanic rocks of samples was obtained on and around the flanks of Mount Somma-Vesuvius volcano, Roccamonfina volcano, Campi Flegrei Volcanic District and Ventotene Island on the basis of detailed field mapping (Rolandi, unpubl. Data); each rocks weighted 2 Kg, then was crushed to ash size, 2 g for each rocks were analyzed for Pb isotopic determinations. At least half of the samples are pumice and the rest are scoria and lava. Pb isotopes were determined at the US Geological Survey, Reston, VA, on a Finnigan-MAT 262 mass spectrometer. Pb isotopic analyses were done on 50 minerals separates (plagioclase, sanidine, and leucite). And 250 whole rocks (total of ~300 samples, **Table 1** and **Table 2**), using static multi-collection mode. Isotopes were separated using standard anion-exchange methods: Pb isotopic ratios were normalized for mass fractionation by 0.1% per mass unit on the basis of repeated runs of NBS-981; Pb blanks during

Table 1. Pb isotopic composition of the volcanic rocks and minerals from Mt. Somma-Vesuvius volcano.

Sample ID		$^{206}Pb/^{204}Pb$	SE(M)2	$^{207}Pb/^{204}Pb$	SE(M)2	$^{208}Pb/^{204}Pb$	SE(M)2
S1a	WR	19.002	0.001	15.625	0.008	38.985	0.002
S1a	WR	19.053	0.003	15.681	0.003	39.169	0.009
S1a	KSP	19.127	0.042	15.752	0.036	39.349	0.092
S1b	WR	19.013	0.003	15.633	0.003	39.014	0.007
S1b	WR	19.041	0.002	15.664	0.001	39.121	0.005
S1b	KSP	19.038	0.007	15.664	0.007	39.124	0.019
S1c	WR	19.023	0.001	15.642	0.001	39.037	0.003
S1c	KSP	19.039	0.002	15.661	0.002	39.105	0.006
S1d	WR	19.002	0.0006	15.610	0.0005	38.935	0.001
S1d	WR	18.994	0.002	15.607	0.001	38.925	0.003
S2(1)	WR	19.030	0.005	15.621	0.005	39.032	0.035
S2(1)	WR	19.033	0.003	15.629	0.003	38.986	0.007
S2(1)	KSP	19.016	0.082	15.640	0.066	39.087	0.166
S2(2)a	WR	19.042	0.006	15.637	0.005	39.013	0.014
S2(2)a	KSP	19.538	0.678	16.040	0.552	39.915	1.459
S2(2)b	WR	18.990	0.006	15.689	0.006	39.149	0.017
S2(2)b	WR	18.931	0.002	15.611	0.001	38.893	0.003
S2(2)c	KSP	18.982		15.682		39.135	
S2(2)e	WR	18.985		15.639		38.987	
S2(3)	KSP	18.979	0.003	15.666	0.003	39.085	0.007
S2(4)	WR	18.958		15.645		39.024	0.003
S3(1)a	KSP	18.949	0.001	15.626	0.001	38.950	
S3(1)b	WR	18.966		15.658		39.067	0.004
S3(1)b	KSP	18.950	0.001	15.629	0.001	38.955	
S3(1)c	WR	18.949		15.637		38.995	0.004
S3(1)c	KSP	18.954	0.001	15.635	0.001	38.978	
S3(1)d	WR	19.004		15.702		39.223	0.009
S3(1)d	KSP	18.947	0.004	15.627	0.003	38.952	
S3(1)e	WR	18.935		15.623		38.946	0.004
S3(1)e	KSP	18.968	0.002	15.652	0.001	39.043	0.006
S3(1)f	WR	18.916	0.002	15.592	0.002	38.830	
S3(2)a	WR	18.960		15.647		39.031	0.004
S3(2)b	WR	18.941	0.002	15.615	0.001	38.914	0.002
S3(2)c	WR	18.937	0.0007	15.613	0.0006	38.904	0.009
S3(2)c	WR	18.909	0.005	15.597	0.003	38.851	0.004
S3(2)d	WR	18.944	0.002	15.622	0.001	38.936	0.001
S3(2)e	WR	18.936	0.0006	15.612	0.0005	38.901	0.007
S3(2)e	WR	18.949	0.002	15.629	0.002	38.956	

Continued

S3(2)f	WR	18.959		15.645		39.025	0.002
S3(3)a	WR	18.940	0.001	15.614	0.001	38.908	
S3(3)a	WR	18.975		15.667		39.098	0.004
S3(3)b	WR	18.956	0.001	15.636	0.001	38.981	
S3(3)b	WR	18.947		15.646		39.015	
S3(3)c	KSP	18.956	0.001	15.638	0.001	38.984	0.004
S3(3)c	KSP	18.975		15.669		39.101	
S3(3)c	WR	18.931	0.0008	15.613	0.0008	38.902	0.002
S3(3)d	WR	18.945	0.0006	15.624	0.0006	38.938	0.002
S4(2)a	WR	18.936	0.0006	15.604	0.0006	38.874	0.001
S4(2)a	WR	18.959	0.004	15.636	0.004	38.980	0.011
S4(2)b	WR	18.963		15.656		39.051	
S4(2)b	WR	18.936	0.0009	15.604	0.0008	38.874	0.002
S4(4)#1	WR	18.944	0.002	15.624	0.002	38.934	0.007
S5(1)b	WR	19.053		15.769		39.430	
S5(1)c	WR	19.034	0.006	15.737	0.006	39.312	0.018
S5(2)a	WR	18.953	0.0007	15.629	0.0007	38.949	0.002
S5(2)a	WR	18.960	0.004	15.647	0.004	39.015	0.014
S5(2)a	KSP	19.001	0.005	15.684	0.005	39.140	0.016
S5(2)a	KSP	19.020		15.715		39.257	
S5(2)b	WR	18.967	0.001	15.648	0.001	39.011	0.004
S5(2)b	KSP	18.979	0.002	15.657	0.002	39.050	0.007
S5(3)a	WR	19.030		15.736		39.320	
S5(3)b	WR	19.011	0.005	15.705	0.004	39.202	0.012
S5(4)b	WR	18.953	0.002	15.609	0.002	38.887	0.005
S5(4)b	WR	18.953	0.0009	15.615	0.0008	38.899	0.002
S6(1)a	WR	18.953	0.0009	15.622	0.0008	38.927	
S6(1)a	KSP	18.950	0.001	15.623	0.002	38.933	0.002
S6(1)b	WR	18.933	0.001	15.603	0.001	38.863	0.006
S6(1)b	KSP	18.944	0.002	15.618	0.002	38.912	0.003
S6(1)c	WR	18.939	0.0008	15.611	0.0007	38.890	0.005
S6(1)c	KSP	18.983	0.003	15.663	0.003	39.069	0.002
S6(2)a	WR	18.971	0.002	15.662	0.002	39.051	0.008
S6(2)a	WR	18.962	0.0008	15.640	0.0008	38.986	0.005
S6(2)a	KSP	19.003	0.009	15.686	0.009	39.140	0.002
S9(1)a	KSP	19.384	0.139	16.041	0.114	40.168	0.027
S9(1)a	KSP	18.995		15.688		39.148	0.298
S9(1)b	KSP	18.978		15.664		39.084	
S9(1)b	Sink	18.959	0.001	15.633	0.001	38.967	

Continued

S9(1)c	KSP	18.987		15.683		39.146	0.003
S9(1)d	WR	18.947	0.001	15.618	0.0009	38.916	
S10(1)a	KSP	18.963	0.002	15.634	0.002	38.960	0.002
S10(1)a	KSP	18.982		15.666		39.076	0.005
S10(1)c	KSP	19.010		15.687		39.161	
S10(1)d	WR	18.959	0.001	15.608	0.001	38.887	
S11(1)	WR	18.948	0.0007	15.622	0.0006	38.913	0.003
S12(2)	WR	18.982		15.695		39.174	0.0016
S13(1)a	WR	18.963	0.008	15.664	0.007	39.057	
S13(1)a	WR	18.963		15.664		39.057	0.017
S13(1)b	WR	18.940	0.001	15.609	0.001	38.881	
S13(2)b	WR	18.974		15.673		39.099	0.003
S14(1)	WR	18.955	0.002	15.641	0.002	38.982	
S14(2)	WR	18.968		15.654		39.032	0.006
S15(1)b	WR	18.949	0.003	15.623	0.003	38.915	
S15(1)b	WR	19.017		15.720		39.261	0.008
S15(2)a	WR	18.998	0.022	15.689	0.018	39.143	
S16(1)	WR	19.044		15.753		39.370	0.044
S17(1)a	WR	19.025	0.006	15.722	0.006	39.252	
S17(2)b	WR	18.929	0.001	15.606	0.0008	38.8613	0.021
S18(1)a	WR	18.901	0.002	15.585	0.001	38.796	0.002
S18(1)b	WR	18.949	0.0008	15.622	0.0008	38.9139	0.005
S19(1)a	WR	19.088	0.071	15.780	0.059	39.400	0.002
S20	WR	19.070	0.004	15.655	0.003	39.068	0.147
S20	WR	19.089		15.687		39.185	0.01
S21(1)a	WR	19.024	0.024	15.646	0.02	39.022	
S21(1)a	WR	19.043		15.677		39.139	0.05
S21(1)b	WR	19.030	0.012	15.677	0.011	39.137	
S21(1)b	WR	19.049		15.709		39.254	0.026
S21(1)c	WR	18.972	0.001	15.614	0.0009	38.906	
S21(1)c	WR	19.035	0.008	15.668	0.007	39.094	0.002
S21(1)c	WR	19.054		15.700		39.212	0.019
S21(2)c	WR	19.125	0.138	15.763	0.109	39.327	
S21(2)d	WR	19.038	0.006	15.673	0.005	39.113	0.276
S21(2)d	WR	19.058		15.704		39.231	0.0145
S21(2)e	WR	18.980	0.0009	15.602	0.0008	38.869	
S21(2)f	WR	18.997	0.001	15.615	0.001	38.916	0.002
S21(2)f	WR	19.016		15.646		39.032	0.004
V1a	WR	18.987	0.002	15.614	0.002	38.911	

Continued

R 1a	WR	19.006		15.646		39.028	0.005
V1b	WR	19.020	0.05	15.647	0.041	39.021	
R 1b	WR	19.040		15.679		39.138	0.102
V1c	WR	19.032	0.003	15.677	0.004	39.111	
R 1c	WR	19.051		15.708		39.229	0.012
V2a	WR	19.096	0.09	15.740	0.079	39.272	
R 2b	WR	18.985		15.646		39.015	0.15
V2b	WR	18.966	0.001	15.615	0.001	38.898	
V3a	WR	18.965	0.002	15.593	0.002	38.852	0.003
R 3a	WR	18.984		15.625		38.969	0.005
V3b	WR	19.054	0.004	15.656	0.002	39.076	
R 3b	WR	19.073		15.688		39.193	0.01
V4	WR	18.989	0.002	15.652	0.002	39.015	
R 4	WR	19.008		15.683		39.132	0.006
V5	WR	19.234	0.2	15.897	0.164	39.622	
V6a	WR	18.935	0.001	15.586	0.001	38.799	0.42
R 6a	WR	18.954		15.617		38.915	0.003
V6b	WR	18.977	0.013	15.639	0.011	38.982	
R 6b	WR	18.996		15.670		39.099	0.028
V6c	WR	18.979	0.009	15.638	0.008	38.976	
R 6c	WR	18.998		15.669		39.093	0.023
V7	WR	19.190	0.199	15.812	0.163	39.402	
V7	WR	19.024	0.001	15.630	0.001	38.885	0.413
V8	WR	18.929	0.008	15.612	0.007	38.874	0.003
R 8	WR	18.948		15.643		38.991	0.017
V9a	WR	18.985	0.01	15.629	0.009	38.932	
R 9a	WR	19.004		15.661		39.049	0.022
V9b	WR	18.967	0.003	15.614	0.002	38.898	
R 9b	WR	18.986		15.645		39.015	0.008
V10	WR	19.101	0.076	15.677	0.062	39.134	
R 10	WR	19.120		15.709		39.252	0.152
V14	WR	19.005	0.008	15.602	0.007	38.894	
V14	WR	19.024		15.633		39.011	0.017
V18	WR	18.999	0.009	15.595	0.008	38.867	
V18	WR	19.018		15.627		38.984	0.02
V21	WR	18.968	0.004	15.633	0.003	38.953	
V21	WR	18.987		15.664		39.070	0.008
V23	WR	18.968	0.006	15.636	0.005	38.976	
V23	WR	18.970	0.001	15.635	0.0009	38.954	0.014

Continued

V23	WR	18.987		15.667		39.093	0.002
V30	WR	18.954	0.001	15.616	0.0008	38.900	
V34	WR	18.980	0.003	15.659	0.002	39.054	0.002
V35	WR	18.985	0.004	15.651	0.004	39.031	0.015
V35	WR	19.004		15.683		39.148	
V42	WR	18.952	0.002	15.621	0.001	38.915	0.004
V42	WR	19.013	0.018	15.683	0.016	39.119	0.049
V42	WR	19.032		15.714		39.236	
V46	WR	18.963	0.001	15.630	0.001	38.935	0.003
V46	WR	18.982		15.661		39.052	
V59	WR	19.030		15.724		39.279	
V64	WR	18.991	0.002	15.632	0.002	38.948	0.005
V84	WR	18.959	0.001	15.614	0.001	38.901	0.002
V84	WR	18.946	0.0008	15.604	0.0008	38.856	0.002
V84	WR	18.942	0.003	15.601	0.003	38.844	0.008
V94	WR	19.178		15.767		39.435	
V97	WR	19.036	0.002	15.615	0.002	38.950	0.05
V97	WR	19.036	0.003	15.616	0.002	38.951	0.006
V102	WR	18.979	0.001	15.628	0.001	38.936	0.003
V102	WR	19.050		15.717		39.228	
V102	WR	19.031	0.029	15.685	0.026	39.110	0.067
V110	WR	18.964	0.001	15.602	0.0009	38.851	0.003
V141	WR	19.056	0.001	15.640	0.001	39.032	0.003
V155	WR	18.964	0.001	15.602	0.0009	38.851	0.003
SCL1	WR	18.988	0.002	15.602	0.002	38.902	0.007
SCD1	WR	18.981	0.003	15.607	0.003	38.891	0.009
SCL1a	WR	19.008	0.003	15.618	0.003	38.955	0.012
SCL3	WR	19.023	0.005	15.628	0.005	39.019	0.015
SCL4	WR	18.993	0.002	15.621	0.002	38.965	0.008
SCL5	WR	18.989	0.002	15.617	0.002	38.959	0.004
SCL6	WR	18.989	0.002	15.642	0.001	39.033	0.004
SCD2#1	WR	19.077	0.003	15.604	0.002	38.975	0.007
S2(2)c	KSP	18.963	0.002	15.650	0.003	39.018	0.008
S3(3)6	KSP	18.943	0.003	15.632	0.002	38.965	0.006

this study were −1 ng. The Pb isotopic data have a total uncertainty of 0.1% (2 s).

4. Discussion

The Pb isotopic composition is presented from mainly the Somma-Vesuvius volcano and cover the eruption ages from Somma caldera activity [<39 Ka (age of the Campanian Ignimbrite)] until the last vulcanian effusive eruption of 1944 AD (**Table 3**, [12], references therein). Then, a representative sample collection of the Campi Fle-

Table 2. Pb isotopic composition of a representative suite of volcanic rocks from Campi Flegrei District (CF), Roccamonfina (RM), Campi Flegrei Breccia Museo (CFb), Ignimbrite Campana (ICB, sanidine and whole rocks: ALT, MTF, SFC, Ve, Sa, Mo, MP), Somma caldera (SCL, SCD), Ventotene xenoliths (Vt).

Samples ID		Petrography	AGE	Lithotype	Pb206/ Pb204	2SE(M)	Pb207/ Pb204	2SE(M)	Pb208/ Pb204	2SE(M)
RM 1	Whole rock	Leuc-theph	1.5 - 0.3 MA	Lava	18.866	0.011	15.749	0.009	39.268	0.026
RM 1	Separate	Ksp			18.739	0.001	15.612	0.001	38.762	0.003
RM 3	Whole rock	K-Basalt	0.3 MA	Lava	18.943	0.006	15.617	0.005	38.968	0.016
RM 3'	Whole rock				19.167	0.004	15.683	0.003	39.209	0.01
RM 5	Whole rock	K-Basalt	0.3 MA	Lava	18.827	0.003	15.684	0.003	39.048	0.009
RM 6	Whole rock	K-Basalt	0.3 MA	Lava	18.839	0.003	15.680	0.003	39.039	0.009
RM 7	Whole rock	Leuc-tephr	1.5 - 0.3 MA	Lava	18.716	0.004	15.605	0.003	38.784	0.008
RM 7	Separate	Ksp			18.749	0.002	15.608	0.001	38.794	0.003
RM 8	Whole rock	K-basalt	0.3 MA?	Lava	19.119	0.002	15.677	0.002	39.177	0.005
RM 10	Whole rock	Latite	0.3 MA	Spatter cone?	19.093	0.002	15.678	0.002	39.173	0.008
RM 12	Whole rock	Trachibasalt	0.3 MA?	lava	18.884	0.003	15.687	0.007	39.080	0.018
CF X	Whole rock	K-Basalt		lava	19.201	0.0009	15.630	0.0007	39.116	0.002
CF 1	Whole rock	Trachibasalt	>40 ky BP	Scoria	19.032	0.004	15.620	0.002	38.948	0.008
CF 2	Whole rock	Trachibasalt	40 - 17 ky BP	Scoria	19.126	0.0006	15.615	0.0005	39.002	0.006
CF 3	Whole rock	Trachibasalt	17,000 y BP	Scoria	18.970	0.001	15.593	0.001	38.837	0.003
CF 5	Whole rock	Latite	?	Scoria	18.971	0.002	15.628	0.001	38.950	0.004
CF 6	Whole rock	Latite	14,000 y BP	Scoria	19.012	0.003	15.647	0.003	39.042	0.009
CF 7	Whole rock	Trachyte	10,000 y BP	Pomice	18.963	0.0007	15.666	0.0006	38.909	0.002
CF 8	Whole rock	Latite	40 - 10 ky BP	Pomice	18.989	0.002	15.638	0.002	38.990	0.007
CF 9	Whole rock	Latite	10 - 4 ky BP	Pomice	18.922	0.002	15.650	0.003	38.965	0.006
CF 10	Whole rock	Trachibasalt	8 - 5 ky BP	Pomice	18.936	0.001	15.580	0.0009	38.798	0.002
CF 10										
CFb 1	Whole rock	Basalt		Lava	18.974	0.002	15.684	0.002	39.082	0.008
CFb 2	Whole rock	Basalt		Lava	18.953	0.002	15.609	0.001	38.855	0.004
CFb 1	Ksp	Basalt			19.044	0.002	15.626	0.002	38.934	0.005
CFb 2	Ksp	Basalt			19.133	0.002	15.615	0.001	39.026	0.004
CFb 3	Ksp	Leuc-tephr.			19.277	0.001	15.659	0.0009	39.211	0.003
CFb 4	Ksp	Leuc-tephr.			19.241	0.002	15.641	0.001	39.138	0.004
ICB 1	Separate	Sanidine	37 - 33 ky BP		19.085	0.002	15.616	0.002	39.011	0.004
ICB 2	Separate	Sanidine	37 - 33 ky BP		19.159	0.003	15.695	0.004	39.266	0.014
ICB 3	Separate	Sanidine	37 - 33 ky BP		19.136	0.005	15.663	0.003	39.179	0.008
ICB 4	Separate	Sanidine	37 - 33 ky BP		19.136	0.005	15.663	0.003	39.061	0.003
ICB 5	Separate	Sanidine	37 - 33 ky BP		19.102	0.001	15.635	0.001	39.064	0.004
ICB HB6a	Separate	Sanidine	37 - 33 ky BP		19.112	0.001	15.649	0.001	39.118	0.005
ICB HB6b	Separate	Sanidine	37 - 33 ky BP		19.114	0.0007	15.642	0.0005	39.085	0.001
ICB HB7a	Separate	Sanidine	37 - 33 ky BP		19.122	0.0007	15.627	0.0006	39.049	0.001
ICB 8	Separate	Sanidine	37 - 33 ky BP		19.023	0.003	15.629	0.002	39.044	0.006
ICB 9	Separate	Sanidine	37 - 33 ky BP		19.128	0.0009	15.635	0.0007	39.078	0.002
ICB 9sec	Separate	Sanidine	37 - 33 ky BP		19.150	0.007	15.678	0.006	39.226	0.006
ICB 10	Separate	Sanidine	37 - 33 ky BP		19.133	0.0007	15.650	0.0006	39.122	0.001
ICB 11	Separate	Sanidine	37 - 33 ky BP		19.093	0.0009	15.625	0.0009	39.026	0.003
ICB 12	Separate	Sanidine	37 - 33 ky BP		19.108	0.0009	15.623	0.0008	39.046	0.002
ICB 13	Separate	Sanidine	37 - 33 ky BP		19.106	0.001	15.625	0.001	39.037	0.003

Continued

ICB 13sec	Separate	Sanidine	37 - 33 ky BP		19.118	0.0009	15.637	0.0008	39.076	0.002
ICB 14	Separate	Sanidine	37 - 33 ky BP		19.097	0.0008	15.621	0.0006	39.020	0.002
ICB 15	Separate	Sanidine	37 - 33 ky BP		19.095	0.006	15.620	0.005	39.024	0.012
ALT 1	Separate	Sanidine	37 - 33 ky BP		19.108	0.001	15.631	0.0008	39.056	0.002
ALT 2	Separate	Sanidine	37 - 33 ky BP		19.147	0.0007	15.670	0.0006	39.190	0.002
ALT 3	Separate	Sanidine	37 - 33 ky BP		19.115	0.0009	15.642	0.0009	39.090	0.003
ALT 4	Separate	Sanidine	37 - 33 ky BP		19.103	0.0006	15.629	0.0004	39.047	0.001
Ponti Rossi	Separate	Sanidine	37 - 33 ky BP		19.095	0.001	15.634	0.0007	39.055	0.002
MTF 1	Separate	Sanidine	37 - 33 ky BP		19.118	0.0006	15.642	0.0005	39.090	0.001
Pian Sorren.	Separate	Sanidine	37 - 33 ky BP		19.128	0.0007	15.633	0.0006	39.070	0.002
SFC 1a	Separate	Sanidine	37 - 33 ky BP		19.094	0.0006	15.631	0.0006	39.045	0.002
SFC 2	Separate	Sanidine	37 - 33 ky BP		19.109	0.0008	15.630	0.0008	39.051	0.002
Ve 1	Separate	Sanidine	37 - 33 ky BP		19.121	0.0005	15.628	0.0004	39.054	0.0009
Sa 1b	Separate	Sanidine	37 - 33 ky BP		19.112	0.0007	15.625	0.0006	39.038	0.001
Mo 1	Separate	Sanidine	37 - 33 ky BP		19.083	0.001	15.602	0.001	38.961	0.004
Mo 2	Separate	Sanidine	37 - 33 ky BP		19.106	0.0009	15.632	0.0007	39.053	0.002
MP 1	Separate	Sanidine	37 - 33 ky BP		19.144	0.001	15.657	0.001	39.151	0.003
MP 1	Separate	Sanidine	37 - 33 ky BP		19.154	0.0008	15.668	0.0007	39.185	0.002
MP 2a	Separate	Sanidine	37 - 33 ky BP		19.120	0.0008	15.626	0.0006	39.049	0.002
MP 2b	Separate	Sanidine	37 - 33 ky BP		19.109	0.001	15.635	0.0008	39.067	0.002
MPI-WB	whole rock		37 - 33 ky BP		19.137	0.001	15.651	0.001	39.133	0.003
VE-1-WB	Whole rock		37 - 33 ky BP		19.166	0.003	15.671	0.003	39.194	0.008
ALT-1-WB	Whole rock		37 - 33 ky BP		19.113	0.002	15.639	0.002	39.080	0.007
Sa 1a-WB	Whole rock		37 - 33 ky BP		19.072	0.003	15.617	0.002	39.067	0.007
Sa 1b-WB	Whole rock		37 - 33 ky BP		19.132	0.0004	15.652	0.0003	39.129	0.0009
ICB 9-WB	Whole rock		37 - 33 ky BP		19.148	0.001	15.656	0.001	39.151	0.005
SCL 1	Whole rock		35 - 25 ky BP	Lava	18.988	0.002	15.602	0.002	38.902	0.007
SCL 1a	Whole rock		35 - 25 ky BP		19.008	0.003	15.618	0.003	38.955	0.012
SCL 3	Whole rock		35 - 25 ky BP		19.023	0.005	15.628	0.005	39.019	0.015
SCL 4	Whole rock		35 - 25 ky BP	Lava	18.993	0.002	15.621	0.002	38.965	0.008
SCL 5	Whole rock		35 - 25 ky BP		18.989	0.002	15.617	0.002	38.959	0.004
SCL 6	Whole rock		35 - 25 ky BP		18.989	0.002	15.642	0.001	39.033	0.004
SCD #2-1	Whole rock		S.Cal. Dykes		19.077	0.003	15.604	0.002	38.975	0.003
Vt 1	Whole rock	Xenlith.			18.815	0.005	15.622	0.005	38.802	0.012
Vt 2	Whole rock	Xenlith.			18.538	0.007	15.603	0.006	38.506	0.019
Vt 3b	whole rock	Xenlith.			18.835	0.003	15.633	0.003	38.810	0.007
Vt 4	Whole rock	Xenolith.			18.757	0.001	15.637	0.001	38.857	0.003
Vt 4	Ksp	Xenolith.			18.765	0.001	15.647	0.001	38.888	0.003
Vt 5a	Whole rock	Xenlith.			18.742	0.002	15.623	0.001	38.810	0.003
Vt 5a	Ksp	Xenolith.			18.753	0.0008	15.629	0.0007	38.832	0.002
Vt 5b	Ksp	Xenolith.			18.737	0.002	15.621	0.002	38.804	0.004
Vt 6	Whole rock	Xenolith.			18.742	0.002	15.653	0.002	38.873	0.005

grei Volcanic District (Campi Flegrei, Procida and Ischia) is also presented. A detailed sampling especially for the separate sanidine very much present in the products of this eruption and several representative whole rocks (age of Campanian Ignimbrite eruption: 39 Ka, [13], **Figure 2**) of the Campanian Ignimbrite eruption and several representative analyses of Roccamonfina volcano [3] and Ventotene xenoliths [14] are also presented. The $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagram is presented with all the above data and the following end members

[MORB [15] [16], Hercynian basement-Calabrian crust [17] [18], all the data worldwide of the shallow sediments and GLOSS (Global Sediment Subducting [19], Plank and Langmuir, 1998), Archean upper crust [16] (**Figure 3**)]. From the Pb-Pb diagram, I envisage that the all Campanian Volcanic Province is formed by three

Table 3. Eruption, age, and explosive tipology of Plinian and interplinian events in the last 25 ky.

Formation	Age	Type of activity	Magmatic groups	Dispersion direction	Volume (km^3)
Codola	25 ka BP	Plinian	I group	S-E	1.4
Post-Codola	25 - 17 ka BP	Strombolian and effusive	I group		
Sarno	17 ka BP	Plinian	I group	E	4.4 - 6
Post-Sarno	17 - 16 ka BP	Strombolian and effusive	I group		
Novelle-Seggiari-Bosco	15 - 14 ka BP	Plinian	I group	N-NE	1.5
Ottaviano	8 ka BP	Plinian	II group	E-NE	2.4
Avellino	3800 BP	Plinian	II group	E-NE	2.5
Protohistorical	3800 - 2700 BP	Vulcanian and strombolian	II group		
Pompei AD 79	79 AD	Plinian	III group	E-SE	~4
Ancient historical	79 - 203 AD	Vulcanian, strombolian and effusive	III group		
Pollena AD 472	472 AD	Plinian	III group	N-NE	1.2
Medieval	472 - 1139 AD	Vulcanian, strombolian and effusive	III group		
1631	1631 AD	Plinian	III group	N-NE	1.1
1631 - 1944	1631 - 1944 AD	Vulcanian, strombolian and effusive	III group		

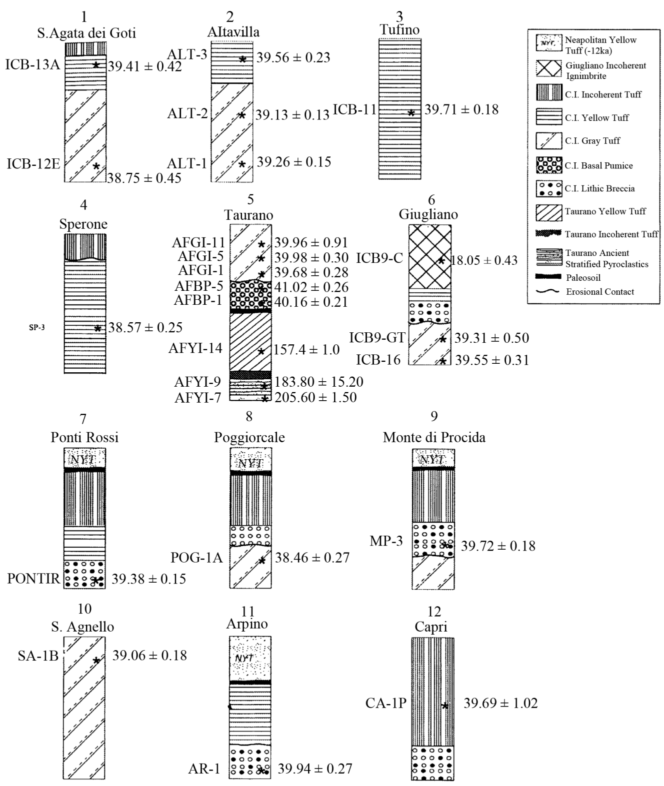

Figure 2. Schematic stratigraphic columns of the Campanian Ignimbrites. Ages are ka and are based on incremental-heating $^{40}Ar/^{39}Ar$ analyses of pure sanidine mineral separates (modified from [13]).

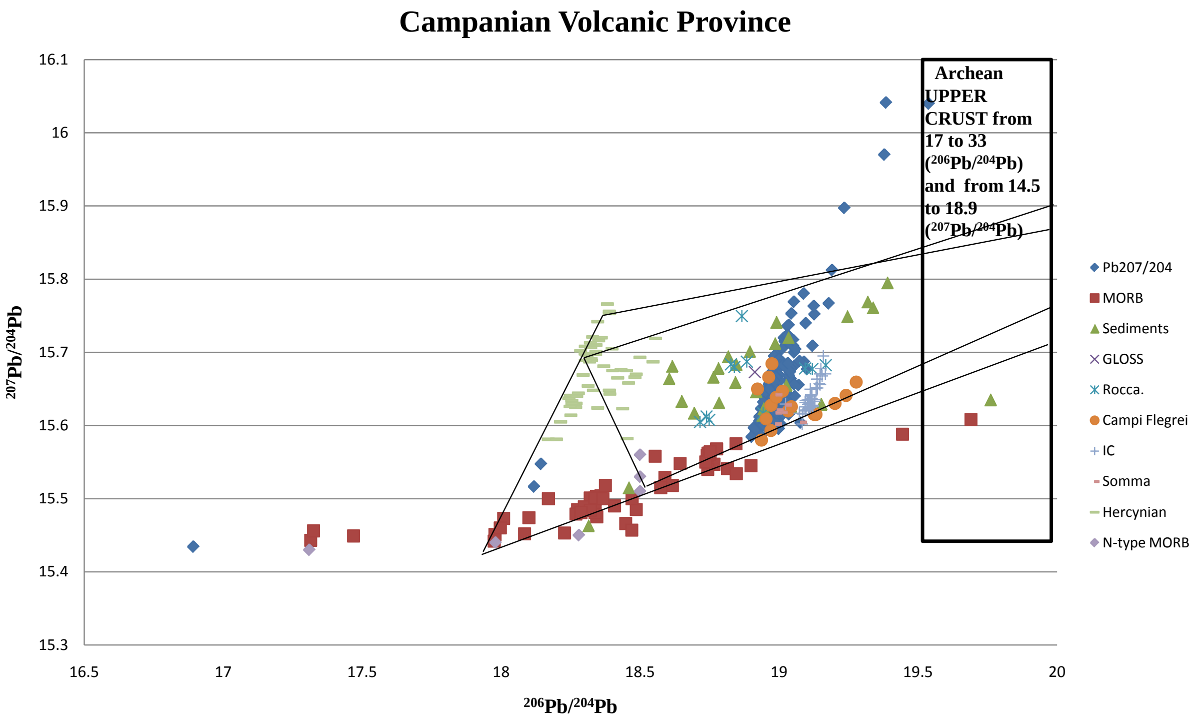

Figure 3. The $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagram is presented with all the above data and the following end members [MORB [15] [16], Hercynian basement-Calabrian crust [17] [18], all the data worldwide of the shallow sediments and GLOSS (Global Sediment Subducting [19], Archean upper crust [16])].

end-menbers: 1) MORB, 2) Hercynian basement, 3) upper crust. This can be computed as I show with different styles of mixing duo to the large range of the end members. Anyhow, the result and interpretation does not change much. The model that I develop is that these volcanic products are produced by signatures of old arching upper crust and then assimilated with the Hercynian basement. Finally, I can also state that the recent sediments [19] are an average between the Hercynian component and the Archean upper crust as can be suggested by the past plate tectonic and the rock cycles.

5. Conclusion

Finally, I can say that the Campanian volcanic products are produced by a MORB component that has been contaminated by a series of upper crust component [20]. Anyhow, I can assume that the distinctive isotopic trend has also been influenced by an Archean upper crust. The magma has also undergone to storage and melting of a Hercynian component as testified by the presence of this kind of basement below the Campanian Volcanic Province. This model has been called deep and hot intrusion zone by [5]. In addition, I state that the GLOSS of [19] are a mixing of the Archean upper crust and Hercynian basement as in rock cycle operating.

Acknowledgements

The Pb isotope data have been produced in the laboratories of USGS, Reston, VA, USA. Thanks to Robert Ayuso to have always hosted me during my PhD. Thanks to the patience of Benedetto De Vivo as tutor during my PhD (1994-1999). Thanks to Chris Hawkesworth for an early review.

References

[1] Paone, A. (2006) The Geochemical Evolution of Somma-Vesuvius Volcano. *Mineralogy and Petrology*, **87**, 53-80. http://dx.doi.org/10.1007/s00710-005-0103-7

[2] Pappalardo, L., Piochi, M., D'Antonio, M., Civetta, L. and Petrini, R. (2002) Evidence for Multistage Magmatic Evolution during the Past 60 kyr at Campi Flegrei (Italy) Deduced from Sr, Nd, and Pb Isotope Data. *Journal of Petroleum*,

43, 1415-1434. http://dx.doi.org/10.1093/petrology/43.8.1415

[3] Paone, A. (2004) Evidence of Crustal Contamination, Sediment, and Fluid Components in the Campanian Volcanic Rocks. *Journal of Volcanology and Geothermal Research*, **138**, 1-26. http://dx.doi.org/10.1093/petrology/43.8.1415

[4] Paone, A. (2013) Petrogenesis of Trachyte and Rhyolite Magmatism on Ponza Island (Italy) and Its Relationship to the Campanian Magmatism. *Journal of Volcanology and Geothermal Research*, **267**, 15-29. http://dx.doi.org/10.1016/j.jvolgeores.2013.09.008

[5] Annen, C. and Sparks, R.S.J. (2002) Effects of Repetitive Emplacement of Basaltic Intrusions on Thermal Evolution and Melt Generation in the Deep Crust. Earth Planet. *Science Letters*, **203**, 937-955. http://dx.doi.org/10.1016/S0012-821X(02)00929-9

[6] Annen, C., Blundy, J.D. and Sparks, R.S.J. (2006) The Genesis of Intermediate and Silicic Magmasin Deep Crustal Hot Zones. *Journal of Petrology*, **47**, 505-539. http://dx.doi.org/10.1093/petrology/egi084

[7] D'Antonio, M., Civetta, L. and Di Girolamo, P. (1999) Mantle Source Heterogeneity in the Campanian Region (South Italy) as Inferred from Geochemical and Isotopic Features of Mafic Volcanic Rocks with Shoshonitic Affinity. *Mineralogy and Petrology*, **67**, 163-192. http://dx.doi.org/10.1007/BF01161520

[8] Scrocca, D., Doglioni, C. and Innocenti, F. (2003) Constraints for an Interpretation of the Italian Geodynamics: A Review. *Memorie descrittive della carta geologica d'Italia Servizio geologico d'Italia*, **62**, 15-46.

[9] Doe, B.R. (1970) Lead Isotopes. Minerals, Rocks and Inorganic Materials. Monograph Series of Theoretical and Experimental Studies 3. Springer, Berlin, 143.

[10] Faure, G. and Mensing, T.M. (2004) Isotopes: Principles and Applications. John Wiley and Sons, Hoboken, 897.

[11] Dickin, A.P. (2005) Radiogenic Isotope Geology. 2nd Edition, Cambridge University Press, Cambridge, 509. http://dx.doi.org/10.1017/CBO9781139165150

[12] Picarelli, L., Evangelista, A., Rolandi, G., Paone, A., Nicotera, M., Olivares, L., Scotto di Santolo, A., Lampitiello, S. and Rolandi, M. (2006) Mechanical Properties and Behaviour of Pyroclastic Soils in Campania Region. *Proceedings of the* 2*nd International Workshop on Characterisation and Engineering Properties of Natural Soils*, Singapore, 29 November-1 December 2006, 2331-2384.

[13] De Vivo, B., Rolandi, G., Gans, P.B., Calvert, A., Bohrson, B.A., Spera, F.J. and Belkin, H.E. (2001) New Constraints on the Pyroclastic Eruptive History of the Campanian Volcanic Plain (Italy). *Mineralogy and Petrology*, **73**, 47-65. http://dx.doi.org/10.1007/s007100170010

[14] De Vivo, B., Torok, K., Ayuso, R.A., Lima, A. and Lirer, L. (1995) Fluid Inclusion Evidence for Magmatic Silicate/Saline/CO_2 Immiscibility and Geochemistry of Alkaline Xenoliths from Ventotene Island, Italy. *Geochimica et Cosmochimica Acta*, **59**, 2941-2953. http://dx.doi.org/10.1016/0016-7037(95)00186-7

[15] Ito, E., White, W.M. and Gopel, C. (1987) The O, Sr, Nd and Pb Isotope Geochemistry of MORB. *Chemical Geology*, **62**, 157-176. http://dx.doi.org/10.1016/0009-2541(87)90083-0

[16] Rollinsson, H.G. (1993) Using Geochemical Data: Evaluation, Presentation, Interpretation. Pearson Education Limited, Harlow, 380.

[17] Rottura, A., Del Moro, A., Pinarelli, L., Petrini, R., Peccerillo, A., Caggianelli, G.M. and Piccarretta, G. (1991) Relationships between Intermediate and Acidic Rocks in Orogenic Granitoid Suites: Petrological, Geochemical and Isotopic (Sr, Nd, Pb) Data from Capo Vaticano (Southern Calabria, Italy). *Chemical Geology*, **92**, 153-176. http://dx.doi.org/10.1016/0009-2541(91)90054-U

[18] Ayuso, R.A., Messina, A., De Vivo, B., Russo, S., Woodruff, L.G., Sutter, J.F. and Belkin, H.E. (1994) Geochemistry and Argon Thermochronology of the Variscan Sila Batholith, Southern Italy: Source Rocks and Magma Evolution. *Contributions to Mineralogy and Petrology*, **117**, 87-109. http://dx.doi.org/10.1007/BF00307732

[19] Plank, T. and Langmuir, C.H. (1998) The Composition of Subducting Sediment and Its Consequences for the Crust and Mantle. *Chemical Geology*, **145**, 325-394. http://dx.doi.org/10.1016/S0009-2541(97)00150-2

[20] Paone, A. (2013) A Review of Carbonatite Occurrences in Italy and Evaluation of Origins. *Open Journal of Geology*, **3**, 66-82. http://dx.doi.org/10.4236/ojg.2013.32011