DR2015284

Supplementary material

1. Products of Cerro Negro

1.1. Petrography

The subvolcanic rocks of the Cerro Negro intrusive complex were characterized as (hornblende) andesites based on qualitative petrographic observations of minerals and textures and especially based on their major element geochemistry (Figures 1 and 2, Table 1 (Supplementary material)).

Hand-specimen of all samples are fine-grained, mesocratic and consist of plagioclase and one or more mafic minerals, mostly of amphibole of variable size and color. The variance in color (grey-green to orange-red) is due to variations in composition, degree of alteration and variation in grain size. Some samples have dark inclusions consisting of hornblende. In thin section, all samples contain phenocrysts of plagioclase (plag), hornblende (hbl), orthopyroxene (opx), clinopyroxene (cpx), Fe-Ti oxides as well as minor amounts of secondary biotite (bt) and chlorite (chl) growing at the expense of plagioclase and pyroxene. Accessory phases include zircon (zr), and apatite (ap) (Figure 1). In general, being intermediate in composition (chemically more evolved than basalts), andesites have lower solidus and liquidus temperatures than basalts. The presence of primary hornblende and possibly biotite indicates that magmas contained some H_2O, i.e. were hydrous. All samples display a plagioclase-pyric texture, where plagioclase is the most abundant mineral and shows oscillatory zoning. Additionally, most samples show signs of weak hydrothermal alteration, possibly as a result of interaction of the magma with the surrounding shales and limestones.

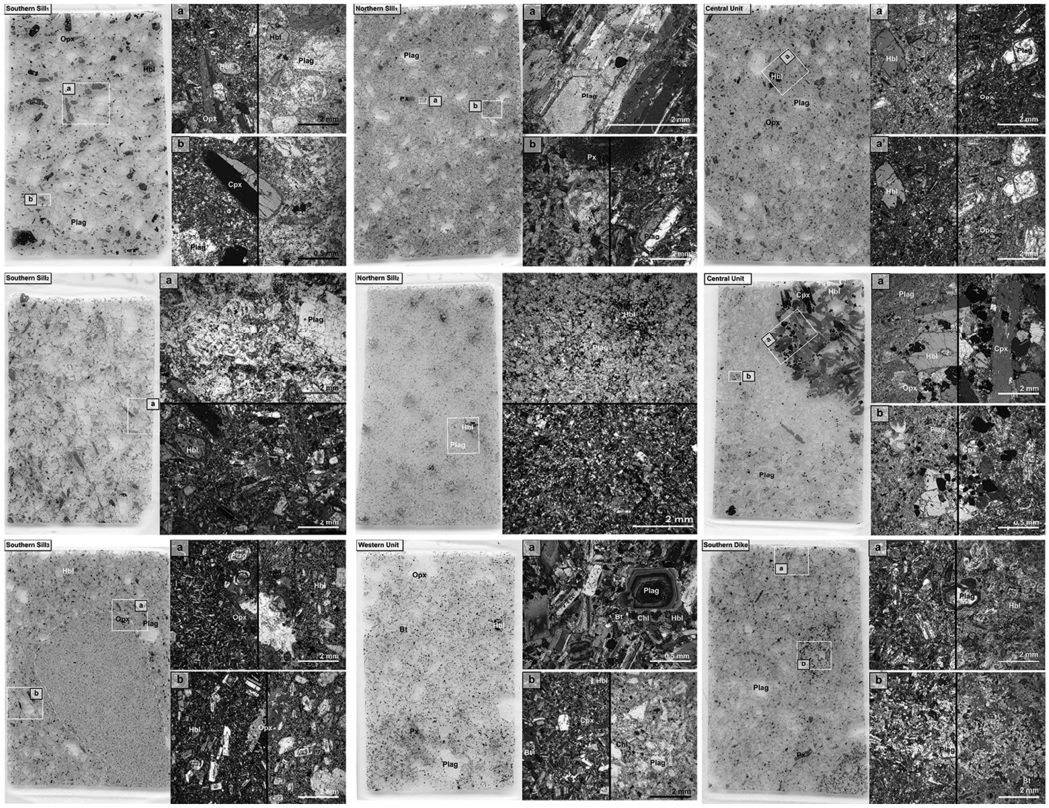

Figure 1: Representative thin sections of subvolcanic rocks from sills and dikes from Cerro Negro. Left hand side of each sample displays the thin section, with locations of micrographs (XPL/PPL) marked by white boxes.

1.2. Major element geochemistry

Major element compositions are listed in Table 1 and overlap with typical andesite compositions, displaying moderate SiO_2 (53-63 wt%), elevated Na_2O (3.2-5.2 wt%), low to moderate TiO_2 (0.58-1.0 wt%), CaO (4.8-7.8 wt%), K_2O (0.57-1.76 wt%) and low to moderate MgO contents (1.97-4.24 wt%). The ratios K_2O/Na_2O (0.11-0.51) and Al_2O_3/Na_2O (3.4-5.5) are low.

The data were plotted into the **T**otal **A**lkali and **S**ilica diagram (TAS) after *Le Maitre* (2002) to classify the different types of volcanic rocks. After recalculating the analyses to volatile-free (H_2O- and CO_2-free), the sum of the Na_2O and K_2O contents (total alkalis, TA) and the SiO_2 content (S) were plotted in Figure 2. Dikes are represented by black filled dots. Open symbols represent sills belonging to different units. The analyzed rocks range from basaltic andesites to andesites and classified as medium-K andesites of the calc-alkaline series. The Cerro Negro magmatic samples were divided into groups based on field relations.

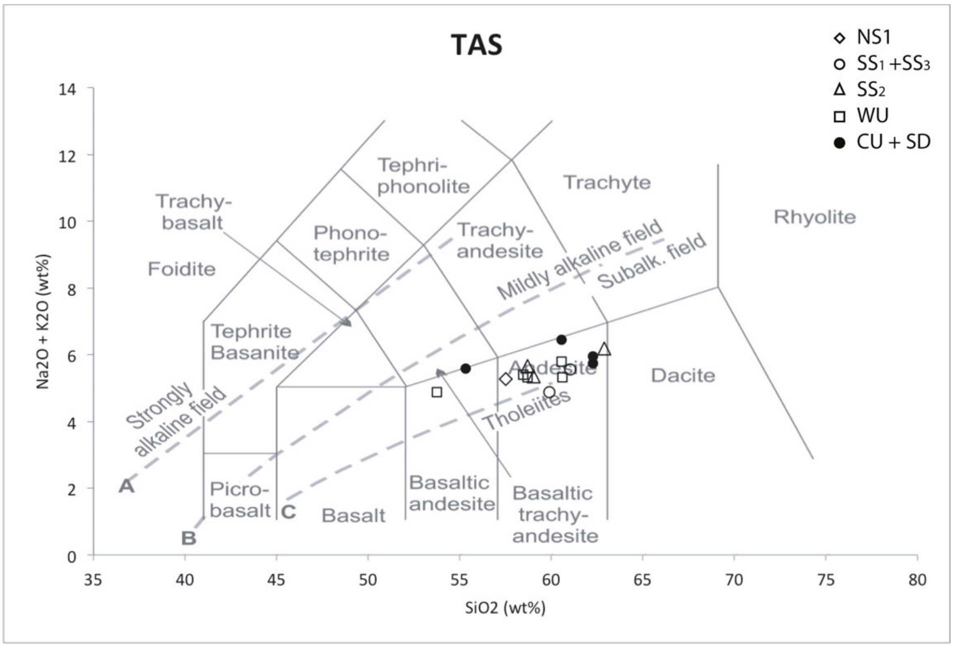

Figure 2: TAS diagram illustrating the compositional range of Cerro Negro magmatic rocks sampled from the different units of the complex.

1.3. Zircon morphology

Zircon grains were obtained from multiple fractions in samples CN-11-01, CN-11-03, CN-11-13, CN-11-14 and CN-11-41.

Sample CN-11-01 was collected from an andesitic sill in the northwestern part of the field area (WP18), close to the contact to Agrio limestones.

The zircon grains from sample CN-11-01 are pale pink and display three morphologies (Figure 3): (a) clear, long prismatic, uneven surfaces, locally affected by resorption, (b) clear, subrounded, uneven surfaces with gas or melt inclusions, locally affected by resorption, and (c) clear, short prismatic, uneven surfaces, inclusion-free, strongly affected by resorption and corrosion. The grains range from 200-300 μm in size and are overall more strongly resorbed than zircon grains from other samples.

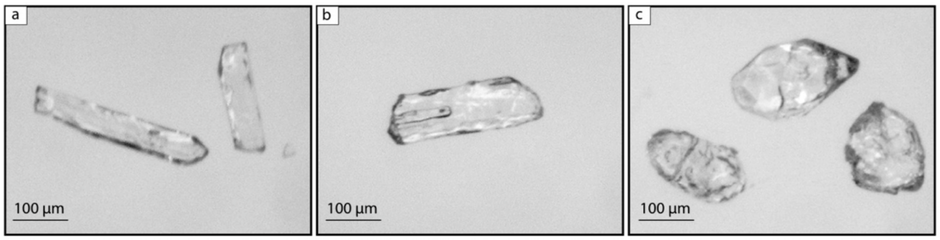

Figure 3: Different zircon morphologies present in sample CN-11-01 after annealing and partial dissolution: (a) clear, long prismatic, uneven surfaces, locally affected by resorption, (b) clear, semi-prismatic, uneven surfaces with fluid or melt inclusions, locally affected by resorption, and (c) clear, short prismatic, uneven surfaces, inclusion-free, strongly affected by resorption.

Sample CN-11-03 yielded different zircon morphologies (Figure 4): (a) clear, short, inclusion-free prisms, (b) clear prisms with fluid or melt inclusions, (c) clear, broken, inclusion-free prisms, and (d) clear, long, inclusion-free prisms. The size of the zircon grains ranges from 150 μm in fraction (a) to 400 μm in the other fractions.

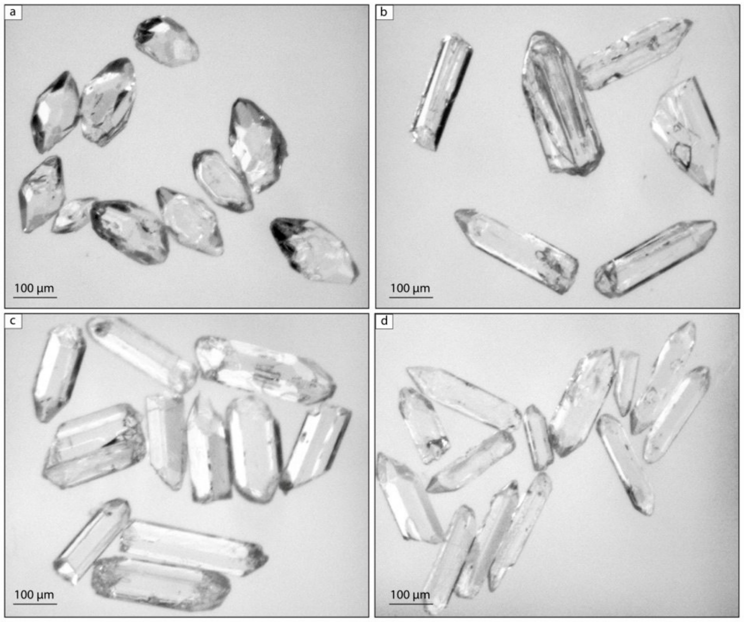

Figure 4: Different zircon morphologies present in sample CN-11-03 after chemical abrasion: (a) clear, short, inclusion-free prisms, (b) clear prisms with gas or melt inclusions, (c) clear, broken, inclusion-free prisms and (d) clear, long, inclusion-free prisms.

CL images of a selection of zircon grains similar to fractions (b)-(d) show well developed oscillatory zoning and two of the grains observed in thin section display sector zoning. Cores are not evident except perhaps in the grain shown in Figure 5a. Quantitative SEM analysis of several inlusions revealed the presence of K-feldspar, albite and apatite inclusions showing that the zircons started growing in the magma at an advanced stage of crystallization.

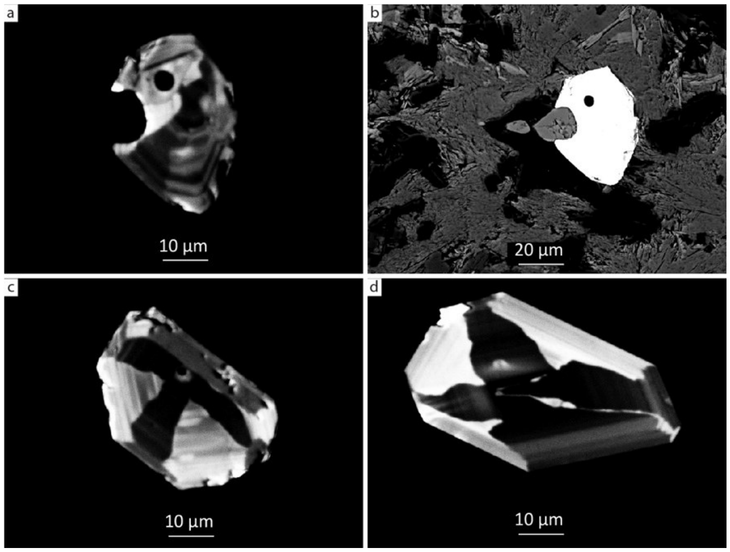

Figure 5: CL (a, c, d) and BSE (b) images of zircon grains from sample CN-11-03. Oscillatory and sector zoning are visible in CL images.

Sample CN-11-13 has two distinct morphologies: (a, b) clear, long, inclusion-free prisms, (c) clear, broken prisms with gas or melt inclusions. The biggest grains are up to 500 µm in size (Figure 6).

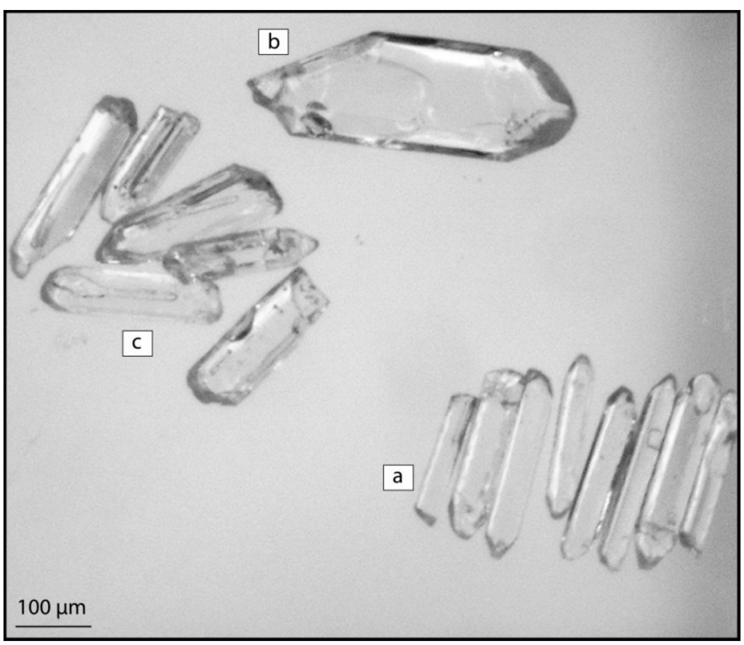

Figure 6: Three different zircon morphologies present in sample CN-11-13 after chemical abrasion: (a, b) clear, long, inclusion-free prisms, (c) clear, broken prisms with gas or melt inclusions.

Cathodoluminescence of prismatic crystals shows well-developed growth zoning and no evidence of cores (Figure 7). The zoning patterns are due to fluctuating trace element concentrations in the parent magma and indicate that the grains are primary magmatic.

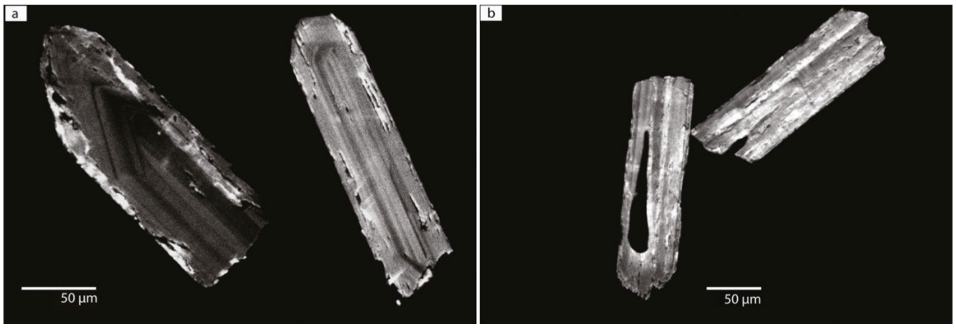

Figure 7: a) CL image of zircon grains with oscillatory zoning from sample CN-11-03, note edges from polishing. b) CL image of zircon grains with inclusions from sample CN-11-13.

Sample CN-11-14 has yielded zircons with two morphologies (Figure 8): (a) clear, long, prismatic grains with smooth surfaces and inclusions (and subsequent corrosion at the edges after chemical abrasion) and (b) clear, short prisms with irregular surfaces and inclusions. The average size of these grains ranges from 200-400 µm.

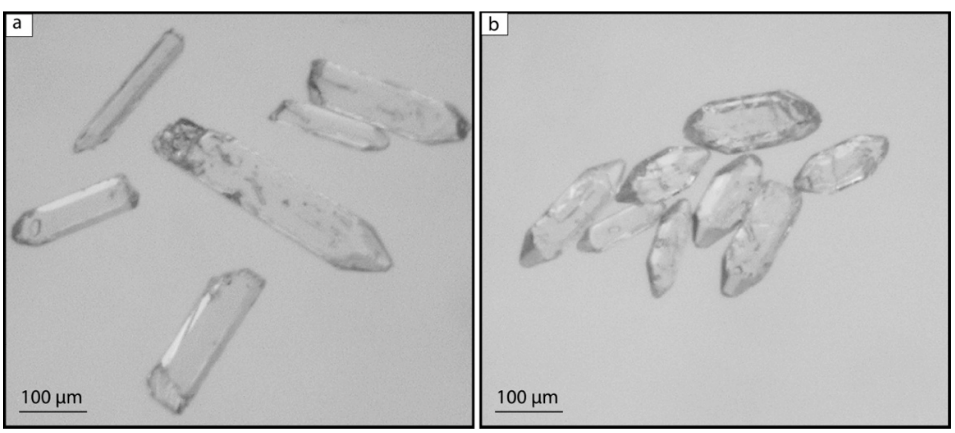

Figure 8: Two different zircon morphologies present in sample CN-11-14 after chemical abrasion: (a) clear, long, prismatic grains with smooth surfaces, inclusions and corrosion at edges after chemical abrasion and (b) clear, short, prisms with irregular surfaces and inclusions.

Sample CN-11-41 was collected from the main dike in the central-southern part of the field area (WP274). Zircon grains in this sample are clear, short prismatic grains or fragments of such with inclusions, clear long prismatic inclusion-free grains, or short/equant grains (Figure 9). The grain size is variable and ranges from 250- 500 μm.

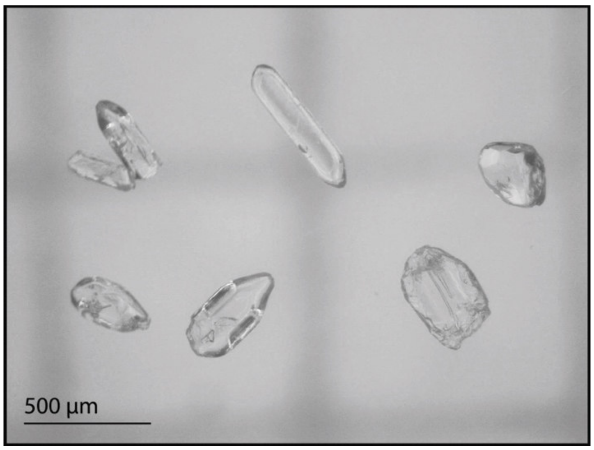

Figure 9: Various zircon morphologies and grain sizes present in sample CN-11-41 after chemical abrasion.

Table 1 Major element data as wt% oxides for Cerro Negro magmatic rocks, recalculated volatile free

Sample	**CN-11-01**	**CN-11-03**	**CN-11-13**	**CN-11-14**	**CN-11-17**	**CN-11-18**	**CN-11-19**	**CN-11-20**	**CN-11-21A**	**CN-11-21B**	**CN-11-23**	**CN-11-25**	**CN-11-26**	**CN-11-28A**	**CN-11-30**
Unit	NS_1	SS_1	SD	CU	SS_3	SS_2	SS_2	CU	WU	WU	WU	WU	WU	CU	SS_1
SiO_2	57.52	61.02	62.27	60.56	62.88	58.72	59.05	55.33	58.48	53.78	60.55	58.72	60.61	62.26	59.88
Al_2O_3	18.77	17.87	17.77	17.89	17.14	18.02	17.87	18.61	18.10	17.81	17.36	18.13	17.73	17.47	18.23
Fe_2O_3	7.84	6.36	5.09	6.89	5.98	7.76	7.73	9.09	7.33	10.58	7.45	7.71	6.74	6.10	5.66
MnO	0.19	0.15	0.11	0.19	0.17	0.16	0.20	0.28	0.20	0.45	0.14	0.21	0.18	0.11	0.20
MgO	2.50	2.06	2.47	2.20	1.97	2.45	2.47	4.23	3.04	4.24	2.45	2.84	2.63	2.03	2.40
CaO	6.90	6.01	5.68	4.84	4.86	6.26	6.38	5.76	6.40	7.06	5.39	6.07	5.86	5.27	7.79
Na_2O	4.40	4.69	5.17	5.04	4.72	4.10	4.06	4.47	4.04	3.22	4.04	4.17	4.07	4.66	4.51
K_2O	0.87	0.87	0.57	1.40	1.48	1.56	1.29	1.10	1.35	1.65	1.76	1.14	1.25	1.28	0.37
TiO_2	0.78	0.65	0.66	0.66	0.58	0.70	0.69	0.95	0.76	1.00	0.66	0.78	0.67	0.59	0.70
P_2O_5	0.23	0.23	0.18	0.25	0.21	0.23	0.24	0.18	0.24	0.20	0.21	0.20	0.23	0.23	0.24
SO_3		0.08	0.01	0.08	0.01	0.03	0.01	0.01	0.05	0.00					
Sum	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
$Na_2O + K_2O$	5.26	5.56	5.75	6.44	6.20	5.66	5.35	5.57	5.39	4.88	5.80	5.31	5.31	5.94	4.88
Zr (ppm)	152	179	151	153	173	132	152	133	153	157	170	139	172	157	162

Table 2 Desciption of field observations with field localities (waypoints WP), GPS positions

WP	Coordinates		m > NN	Bedding		Contact plane			Sample
	S	W		Az	Dip	Az	Dip		
3	-37.13370	-70.24388	1653	164	44				
4	-37.12902	-70.24136	1611	272	84				
5	-37.13186	-70.24734	1608	234	28				
6	-37.09526	-70.29472	1675	92	47				
8	-37.10117	-70.28899	1730	102	47				
9	-37.10196	-70.28541	1742	270	64				
10	-37.11207	-70.27539	1638	114	46				
13	-37.06686	-70.31892	1387	74	44				
17	-37.18398	-70.26096	1444	72	20				
18	-37.08634	-70.29804	1669			124	45	locally discordant	CN-11-01
21	-37.13036	-70.38467	1092	85	84				
23	-37.11017	-70.31019	1827	146	37				
24	-37.11148	-70.31056	1861	121	28				
25	-37.11493	-70.30791	1861	142	30				
26	-37.11659	-70.31654	1988	80	12				
27	-37.11713	-70.31873	2015	85	81				
28	-37.11765	-70.31933	2031	266	67				
29	-37.11829	-70.32066	2077	176	66				
30	-37.11914	-70.32111	2098	88	55				
31	-37.11952	-70.32263	2139	178	85				
32	-37.11972	-70.32267	2146			46	46	±concordant	CN-11-03
33	-37.11921	-70.32352	2175	37	32	64	35	±concordant	
34	-37.11458	-70.31883	1996	276	14				
35	-37.11027	-70.31452	1885	284	80			concordant	
36	-37.11034	-70.31410	1880					discordant	
37	-37.11037	-70.31375	1877					unclear	
38	-37.11043	-70.31341	1870					unclear	
39	-37.11007	-70.31291	1853					unclear	
40	-37.10544	-70.30901	1817	32	22				
41	-37.10438	-70.31074	1870	192	17			concordant	
42	-37.10505	-70.31651	1967	98	43				
43	-37.10516	-70.31694	1980	235	41				
44	-37.10480	-70.31844	2029	170	10				
45	-37.10361	-70.32057	2068	216	29				
46	-37.10313	-70.32215	2070	195	21				
47	-37.10256	-70.31922	2113	184	24				
49	-37.10089	-70.31662	2035	202	14	201	10	concordant	
53	-37.10009	-70.31101	1977	89	12	123	19	±concordant	
54	-37.10088	-70.31272	1975					locally discordant	
55	-37.10075	-70.31248	1971	180	20				
56	-37.10190	-70.31239	1947			229	34	locally discordant	

WP	Coordinates		m > NN	Bedding		Contact plane			Sample
59	-37.08195	-70.31591	1637					discordant	
60	-37.08174	-70.31474	1633					locally discordant	
61	-37.08118	-70.31392	1640					concordant	
62	-37.08064	-70.30710	1647			338	24	±concordant	
63	-37.08058	-70.30634	1640			14	35	±concordant	
64	-37.07976	-70.30669	1637					±concordant	
66	-37.09093	-70.31083	1810			329	12	±concordant	
67	-37.09059	-70.31152	1812					±concordant	
68	-37.08210	-70.31594	1642					±concordant	
69	-37.06138	-70.36109	1234	279	60				
72	-37.07867	-70.35611	1295					locally discordant	
73	-37.07930	-70.35597	1257	293	47				
74	-37.07940	-70.35530	1262	288	48				
75	-37.07930	-70.35485	1273	290	44				
76	-37.07919	-70.35367	1292	74	19				
77	-37.08034	-70.35349	1282	101	45				
78	-37.08148	-70.35400	1289	118	29				
79	-37.08213	-70.35400	1297	94	30				
81	-37.08333	-70.35473	1346					±concordant	
83	-37.05802	-70.36766	1221	272	39				
87	-37.19862	-70.37314	1017	69	84				
88	-37.19877	-70.37035	1104	254	74				
89	-37.19827	-70.36913	1101	252	63				
90	-37.19695	-70.36510	1094	254	74				
94	-37.19462	-70.35028	1122	81	50				
95	-37.19445	-70.34619	1176	275	84				
97	-37.19347	-70.34612	1181	77	66				
99	-37.18958	-70.34809	1140	74	36				
101	-37.19133	-70.35385	1101	30	12				
102	-37.19140	-70.35545	1096	341	12				
104	-37.17303	-70.26961	1354	84	34				
105	-37.17263	-70.27067	1342	78	21				
106	-37.17872	-70.27040	1337	72	26				
107	-37.15601	-70.27568	1379	89	12				
109	-37.16601	-70.27971	1364	285	14				
110	-37.18346	-70.28824	1345	96	85				
111	-37.17616	-70.27916	1320	268	30				
112	-37.16580	-70.28983	1378	80	89				
113	-37.16575	-70.29030	1389	72	90				
115	-37.16347	-70.29277	1422	250	70				
117	-37.15547	-70.27993	1393	82	24				
119	-37.15369	-70.27954	1406	113	46				
120	-37.15443	-70.28122	1412	109	63				
121	-37.15370	-70.28178	1417	288	26				
122	-37.18471	-70.37287	1064	264	90				

WP	Coordinates		m > NN	Bedding		Contact plane			Sample
123	-37.18506	-70.37139	1062	262	74				
124	-37.18282	-70.36957	1108	279	76				
125	-37.18114	-70.36840	1124	276	67				
126	-37.18059	-70.36778	1125	49	45				
127	-37.17999	-70.36831	1112	77	90				
129	-37.17668	-70.36473	1140	60	48				
130	-37.17466	-70.36022	1151	283	48				
131	-37.17652	-70.35494	1172	270	39				
132	-37.17815	-70.35245	1196	256	56				
133	-37.17818	-70.35219	1203	42	61				
136	-37.17794	-70.35013	1211	68	42				
138	-37.17487	-70.34846	1243	40	84				
139	-37.17475	-70.35068	1212	243	63				
140	-37.17488	-70.35148	1197	57	35				
141	-37.19305	-70.37336	1041	248	80				
144	-37.14677	-70.28926	1475	258	70				
145	-37.14764	-70.28754	1461	256	76				
147	-37.15652	-70.28137	1391	126	19				
148	-37.16511	-70.28460	1354	256	86				
149	-37.16131	-70.28190	1367	243	19				
151	-37.17737	-70.28189	1329	259	79				
153	-37.05352	-70.33183	1326	292	10				
154	-37.06130	-70.32305	1371	107	46				
155	-37.06801	-70.32243	1426	111	47				
156	-37.07909	-70.32027	1513	46	34				
157	-37.08050	-70.31988	1522	68	29				
158	-37.05383	-70.34524	1298	286	44				
159	-37.07740	-70.36777	1216	286	84				
160	-37.08604	-70.36777	1249	104	66				
164	-37.09451	-70.36146	1359			306	22	±concordant	
165	-37.09994	-70.37751	1181	96	75				
166	-37.10625	-70.39695	1188	232	6				
167	-37.23612	-70.36683	1003	96	38				
168	-37.21956	-70.37829	1042	246	50				
169	-37.21766	-70.37144	1003	67	74				
170	-37.12172	-70.39731	1121	216	18				
172	-37.15789	-70.39990	1083	246	3				
174	-37.18258	-70.29284	1368	90	73				
175	-37.18227	-70.29584	1385	74	52				
176	-37.18227	-70.29683	1390	85	78				
177	-37.18275	-70.29786	1398	83	71				
178	-37.18564	-70.30160	1459	259	66				
180	-37.18711	-70.30179	1502					discordant	
181	-37.18107	-70.31057	1577					discordant	
182	-37.18082	-70.31103	1587					discordant	

WP	Coordinates		m > NN	Bedding		Contact plane			Sample
183	-37.18048	-70.31092	1586					discordant	
184	-37.18021	-70.31099	1577					discordant	
185	-37.17971	-70.31105	1588					discordant	CN-11-13
186	-37.17861	-70.31136	1572	81	31				
187	-37.17629	-70.31162	1534	288	30				
190	-37.17283	-70.30897	1597			63	36	concordant	
191	-37.17192	-70.30737	1624	47	56				
192	-37.17309	-70.30688	1562	62	40				
194	-37.10749	-70.32789	2095			77	66	discordant	CN-11-14
195	-37.10839	-70.32811	2133	159	11	246	78	discordant	
196	-37.10725	-70.32629	2068	265	32				
197	-37.10700	-70.32446	2035			158	20	concordant	
198	-37.10643	-70.32461	2035					concordant	
199	-37.10586	-70.33050	2010	297	21	162	79	discordant	
199	-37.10586	-70.33050	2010			233	12	concordant	
200	-37.10527	-70.33197	1956	288	10	285	16	concordant	
201	-37.10096	-70.33618	1849	254	66	252	48	±concordant	
202	-37.10252	-70.32703	1970	304	54				
203	-37.10231	-70.32628	1977	306	35				
205	-37.10225	-70.32459	2015	232	10				
206	-37.10370	-70.32442	2051	168	14			discordant	
207	-37.13114	-70.37871	1161	79	78				
208	-37.14037	-70.33317	1695	248	44	250	46	concordant	
210	-37.13854	-70.32583	1864	246	18			discordant	
211	-37.13855	-70.32335	1957	256	16				
213	-37.13825	-70.31884	2045	60	56				
214	-37.13729	-70.31647	2135	69	29	36	49	±concordant	
215	-37.14053	-70.32198	1962	213	7				
216	-37.14101	-70.32459	1915	294	18				
217	-37.14073	-70.32523	1898					discordant, crosscutting	
218	-37.14019	-70.32523	1866					discordant, crosscutting	
219	-37.13735	-70.34084	1646	251	42				
226	-37.13365	-70.34023	1778	256	52				
227	-37.14538	-70.32595	1716	240	41	240	41	concordant	
228	-37.15194	-70.33144	1529	247	58				
229	-37.15400	-70.33223	1476	247	61				
230	-37.15655	-70.33373	1416	239	41				
232	-37.15790	-70.33454	1401						
233	-37.15918	-70.33607	1367	130	17				
234	-37.15917	-70.33663	1358	94	32				
235	-37.15986	-70.34104	1321	92	52				
236	-37.16127	-70.34325	1298	94	28				
237	-37.16305	-70.34529	1282	265	19				
242	-37.12286	-70.33032	2496	291	15	160	70	discordant	
243	-37.37957	-70.27273	849	59	57				

WP	Coordinates		m > NN	Bedding		Contact plane			Sample
244	-37.13873	-70.30866	1814	91	84				
245	-37.13832	-70.30884	1826	83	66	83	66	concordant	
249	-37.12754	-70.32708	2523	36	19				
250	-37.12808	-70.32464	2438	246	32			discordant	
252	-37.09389	-70.32534	1762	278	11				
253	-37.09683	-70.32411	1866	86	85	46	24	discordant	
254	-37.10152	-70.32954	1826	236	12				
255	-37.10047	-70.33058	1774	275	24	294	17	concordant	
256	-37.09848	-70.33264	1722	284	18				
257	-37.09647	-70.33423	1630	269	40				
258	-37.08969	-70.33728	1521	329	30				
259	-37.08547	-70.33725	1493	94	22				
260	-37.08498	-70.33883	1451	133	18				
265	-37.12537	-70.29410	1968	119	32				
266	-37.12074	-70.29378	1895	94	75				
268	-37.09037	-70.28554	1779	87	84				
269	-37.15542	-70.31035	1667			87	76	concordant	
270	-37.15671	-70.31160	1725	102	24	102	24	concordant	
271	-37.15748	-70.31249	1747	84	20				
274	-37.15374	-70.32115	1750						CN-11-41