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Characterizing deep groundwater using evidence from oil and gas exploration wells in the Lower Kutai Basin of Indonesia

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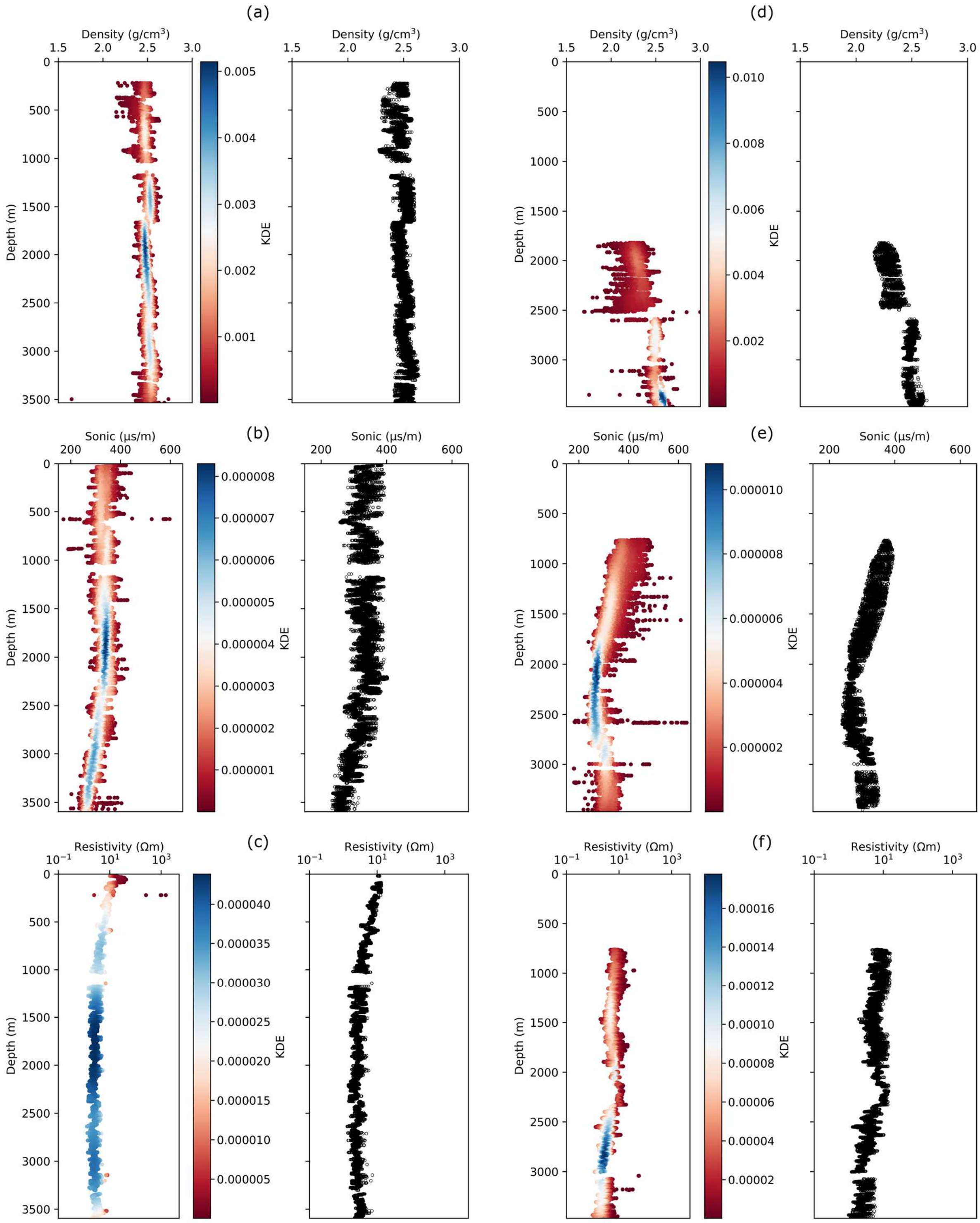


Fig S1 Examples of wireline logs (density, sonic, and resistivity) filtering using Kernel Density Estimation (KDE) in Python at Wells no. 1 (**a, b, c**) and Well no. 6 (**d, e, f**); the original logs are in red to blue whereas the filtered logs are in black; data were provided by PUSDATIN, data center of the Ministry of Energy and Mineral Resources in Indonesia.

Table S1 Hydrochemical data employed in this study from PUSDATIN, data center of the Ministry of Energy and Mineral Resources in Indonesia.

Well	Depth (m)	TDS (mg/L)	NaCl (mg/L)	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	CO_3^{2-}	SO_4^{2-}
1	3295	13394	10305	8.00	4696	n.a.	77	5	5609	2780	0	226
2	671	16886	9803	7.30	1153	n.a.	3800	583	8650	2700	0	0
3	702	1045	263	8.12	263	n.a.	40	6	0	464	15	257
3	1083	2000	422	8.30	422	n.a.	85	49	0	927	44	472
3	1287	837	214	8.02	214	n.a.	30	2	0	426	15	151
3	1715	5220	3715	7.75	1762	n.a.	40	21	1953	1208	0	236
4	3818	11465	9313	n.a.	3340	126	1043	20	5973	951	0	12
5	2575	36142	31212	8.30	12619	846	299	48	18592	2803	13	921
5	2672	19961	15468	7.88	6667	216	328	29	8802	3549	0	371
6	3359	9017	6259	7.90	3064	n.a.	45	21	3195	2005	0	686
7	1327	30256	18047	8.00	10047	n.a.	160	49	8000	7100	400	4500
8	1030	5929	3277	8.75	1821	n.a.	90	58	1456	1257	65	1182
8	1111	4907	2651	8.50	1533	n.a.	45	40	1118	1174	49	948
8	1174	7426	4279	8.70	2451	n.a.	40	18	1828	1601	104	1385
8	1176	2332	1182	7.85	649	n.a.	40	30	533	1080	0	0
8	1247	7296	4054	8.50	2403	n.a.	30	18	1651	1473	76	1644
8	1616	10052	5119	9.70	3521	n.a.	25	3	1598	2315	1417	1173
8	1737	9288	5548	8.10	3028	n.a.	35	12	2521	3229	60	404
8	1948	9114	4781	8.50	2935	n.a.	30	22	1846	2697	136	1447
8	2322	12784	7448	8.75	4253	n.a.	60	24	3195	3279	403	1569
8	2339	16944	10581	8.80	5789	n.a.	20	30	4793	3921	479	1912
8	2413	8675	4373	10.40	3130	n.a.	50	18	1243	299	1460	2475
9	2474	30936	26662	7.62	11165	54	500	52	15497	3666	0	2
9	2533	28194	24021	7.19	10080	50	408	51	13941	3660	0	5
9	2680	26674	22877	7.60	9360	54	467	27	13517	3245	0	5
9	3176	25613	22685	7.80	8835	62	817	20	13850	2025	0	5
10	2411	28595	26133	6.84	10567	31	218	45	15567	2131	0	37
10	3232	23039	20525	6.67	8100	95	138	20	12425	2155	0	105
10	3419	16325	13765	6.74	5600	69	106	8	8165	2322	0	55
10	3498	29660	27818	7.21	10600	142	502	25	17218	1108	0	65
11	3226	19728	17670	6.77	7550	n.a.	227	16	10120	1710	0	105
12	2972	17798	13619	6.87	6040	47	293	30	7579	3779	0	31
12	3438	9595	7242	7.15	3150	35	173	4	4092	2040	0	102
12	3454	11350	8653	7.30	3925	33	50	3	4728	2594	0	17
12	3483	9556	7650	6.80	3100	45	245	4	4550	1609	0	2
13	3653	16508	15006	6.98	5990	67	71	8	9016	1310	0	45
13	3850	11742	9755	7.16	4075	17	93	4	5680	1840	0	33
13	3852	12180	10272	7.49	4322	21	213	4	5950	1630	0	40
14	2268	4145	1463	7.51	1104	68	4	30	359	2578	0	2
15	1643	3589	2058	8.36	1170	12	6	19	888	1015	113	366
15	1665	2643	1162	8.81	834	8	4	3	328	970	113	383

Well	Depth (m)	TDS (mg/L)	NaCl (mg/L)	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	CO_3^{2-}	SO_4^{2-}
15	2138	3586	1407	8.52	1100	13	2	3	307	1501	120	540
15	2215	10834	3913	8.62	3302	17	2	2	611	5100	480	1320
16	3392	22153	12923	7.81	7066	n.a.	120	30	5858	8679	0	399
17	497	424	123	8.47	94	n.a.	16	10	28	250	26	0
18	1474	784	394	7.30	225	n.a.	17	4	170	339	0	29
18	1553	2198	918	7.93	589	n.a.	66	6	329	1141	0	67
18	1605	1567	609	7.58	425	n.a.	31	6	184	866	0	55
18	1751	1312	354	7.02	261	n.a.	100	5	93	822	0	32
18	1924	821	351	7.70	231	n.a.	15	4	120	374	0	77
18	2005	470	183	7.21	109	n.a.	26	5	74	230	0	27
19	3244	20593	18612	8.85	7784	n.a.	53	26	10828	1041	229	633
20	3715	11093	8781	8.92	3939	73	29	6	4842	2058	136	11
20	3774	10872	8878	8.56	3887	65	35	6	4990	1811	61	17
20	4076	10198	7974	8.93	3666	48	9	4	4308	1879	195	88
20	4248	8503	5727	9.00	2936	37	13	2	2791	2301	307	115
21	3950	16664	14471	6.80	6169	49	99	12	8302	1989	0	45
21	3728	13405	11716	6.90	4750	73	350	9	6966	1246	0	12
22	3434	15604	13377	7.20	5370	44	365	6	8007	1806	0	7
22	3656	7358	3729	6.93	900	1875	320	10	2829	1385	0	40
23	1731	3209	1151	7.33	925	17	19	11	226	2001	0	10
23	1822	750	229	7.43	191	10	10	10	38	488	0	2
23	3482	11972	9043	7.08	4030	25	55	7	5013	2830	0	12
23	3566	12401	9007	7.51	4030	31	50	26	4977	3281	0	6
24	3496	19236	16891	7.67	6425	74	407	182	10466	1182	0	500
25	2934	22273	18512	7.35	6868	58	1045	31	11644	2623	0	4
26	3505	11941	7993	6.89	4070	29	62	3	3923	3733	0	120
26	3507	11875	8196	7.58	4060	25	51	3	4136	3451	0	150
26	3514	8769	6275	7.76	2760	33	200	2	3515	2089	0	170
26	3562	13422	9844	6.78	4750	22	49	3	5094	3354	0	150
27	3535	13061	10459	7.65	4495	38	129	3	5964	2301	0	130
27	3543	14377	11780	7.68	4385	58	695	13	7395	1661	0	170
27	3744	15257	12874	7.42	4865	54	613	15	8009	1597	0	105
28	3477	14275	11426	7.57	4425	55	730	12	7001	1989	0	64
28	3485	10340	7583	7.28	3144	40	475	5	4440	2196	0	40
29	3422	10202	6577	n.a.	3382	n.a.	50	24	3195	3010	68	473
29	3742	10087	5998	n.a.	3247	n.a.	50	21	2751	3650	31	337
29	3895	21810	17987	n.a.	7869	n.a.	60	61	10118	2768	0	934
29	3949	22202	18381	n.a.	8086	n.a.	40	55	10295	2652	155	919
30	3332	20008	15985	6.74	5160	66	2120	24	10825	1814	0	0
32	2707	21612	18386	7.39	7266	76	552	29	11120	2493	4	71
33	3368	16555	12993	7.35	5820	30	167	7	7173	3355	0	3
33	3550	16288	13444	6.74	5500	497	292	8	7944	2048	0	0
33	3642	12854	8103	7.94	4140	273	75	2	3963	4399	0	2
33	3644	11188	7630	7.56	3678	36	175	3	3952	3342	0	2
34	3446	13113	9760	7.26	4386	35	94	7	5374	3209	0	8

Well	Depth (m)	TDS (mg/L)	NaCl (mg/L)	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	CO_3^{2-}	SO_4^{2-}
34	3667	17521	15304	7.58	6076	42	265	10	9228	1891	0	9
34	3714	13621	10731	7.83	4331	46	423	14	6400	2403	0	4
34	3898	10829	8844	7.87	3774	20	100	3	5070	1860	0	2
35	3847	8693	5594	7.34	2825	35	119	3	2769	2934	0	8
35	4004	15617	12716	7.57	4125	90	1550	10	8591	1171	0	80
35	4148	9828	6800	7.35	3250	35	90	3	3550	2830	0	70
36	3600	18944	17349	7.60	6650	34	323	20	10699	1190	0	28
36	3611	12513	11594	8.60	4530	30	250	8	7064	566	60	6
36	3732	20968	18891	8.20	7300	39	345	22	11591	1632	9	30
36	3800	22841	21450	8.30	8650	36	275	12	12800	1050	16	3
36	3824	19184	18439	7.90	6700	34	545	15	11739	151	0	1
36	3864	27993	26459	8.10	10750	39	160	19	15709	1283	18	15
37	3486	16383	14156	7.40	5085	16	980	16	9071	1214	0	1
37	3596	13723	10549	7.50	4930	26	11	3	5619	3127	0	8
38	1127	27577	25824	7.74	10209	68	312	75	15615	1296	0	3
38	3106	24433	15656	6.74	6950	67	750	19	8706	7761	0	180
39	3784	18405	16282	6.70	6520	206	83	8	9762	1806	0	20
40	3266	12658	10312	n.a.	4490	48	285	30	5822	1981	0	2
41	3182	17393	14413	7.05	6390	44	94	10	8023	2808	0	24
42	2311	34329	29220	n.a.	11559	n.a.	1211	60	17661	2238	0	1600
42	2807	24895	19047	n.a.	7154	n.a.	1424	243	11893	3331	0	850
43	3069	19344	15990	7.53	6400	46	448	15	9590	2570	0	275
43	3083	16028	12875	7.59	5450	38	180	8	7425	2776	0	150
43	3123	17907	15060	7.64	5650	56	748	14	9410	1915	0	115
43	3149	14414	11380	7.82	5240	31	65	8	6140	2830	0	100
44	2880	24442	19134	n.a.	6585	131	2432	13	12549	2113	0	619
44	2928	21763	16911	n.a.	6705	112	1352	21	10206	2522	0	845
44	2994	15965	12035	n.a.	4580	101	1004	25	7455	2514	0	286
44	3017	14366	10868	n.a.	4655	95	492	7	6213	2507	0	397
45	2583	34767	32057	7.24	12350	70	590	61	19707	1989	0	0
45	2880	22535	19339	6.94	8050	50	195	17	11289	2934	0	0
Seawater		36307	30335	n.a.	10810	390	420	1245	19525	122	0	3795

n.a.: not available

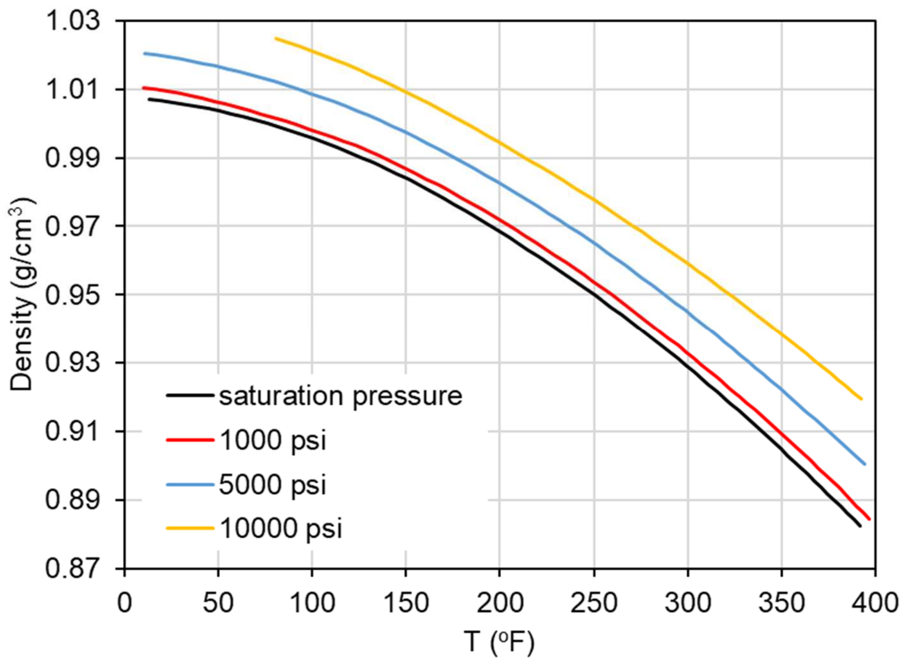


Fig. S2 Density of pure water as a function of temperature and pressure (Numbere et al. 1997)

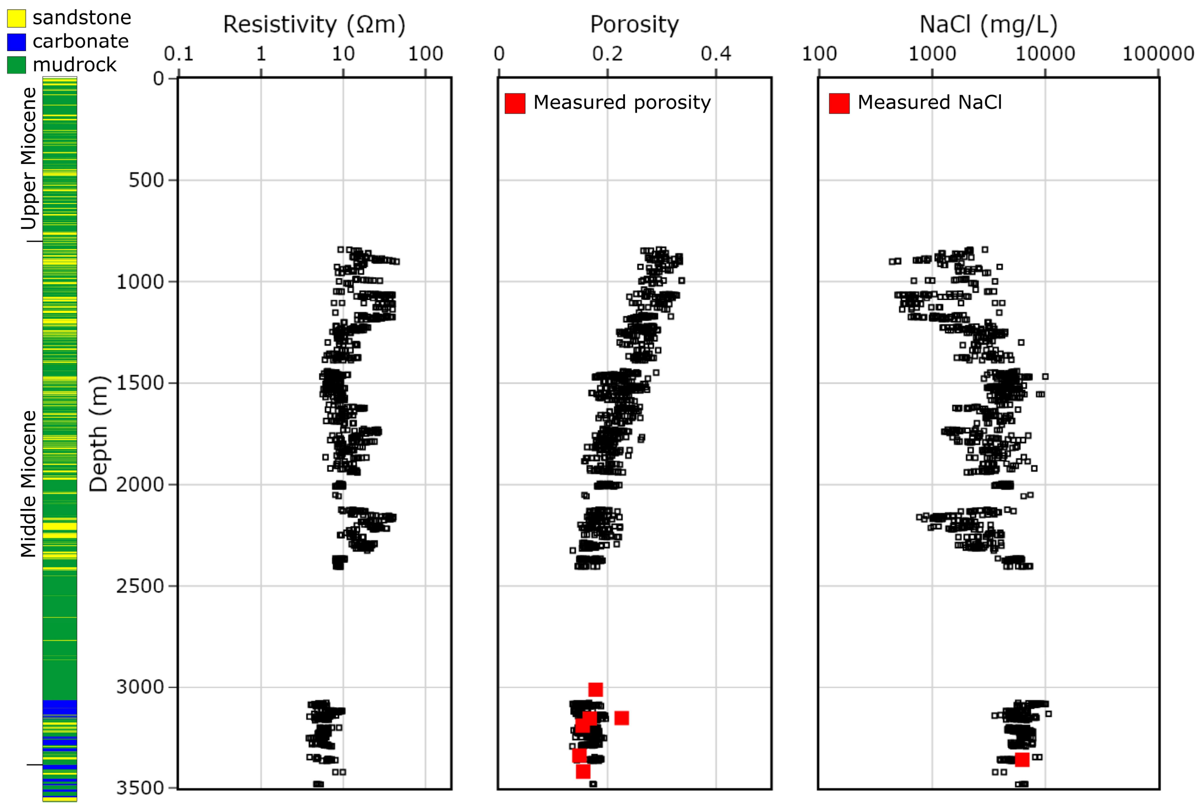


Fig. S3 The result of NaCl estimation at Well no. 6

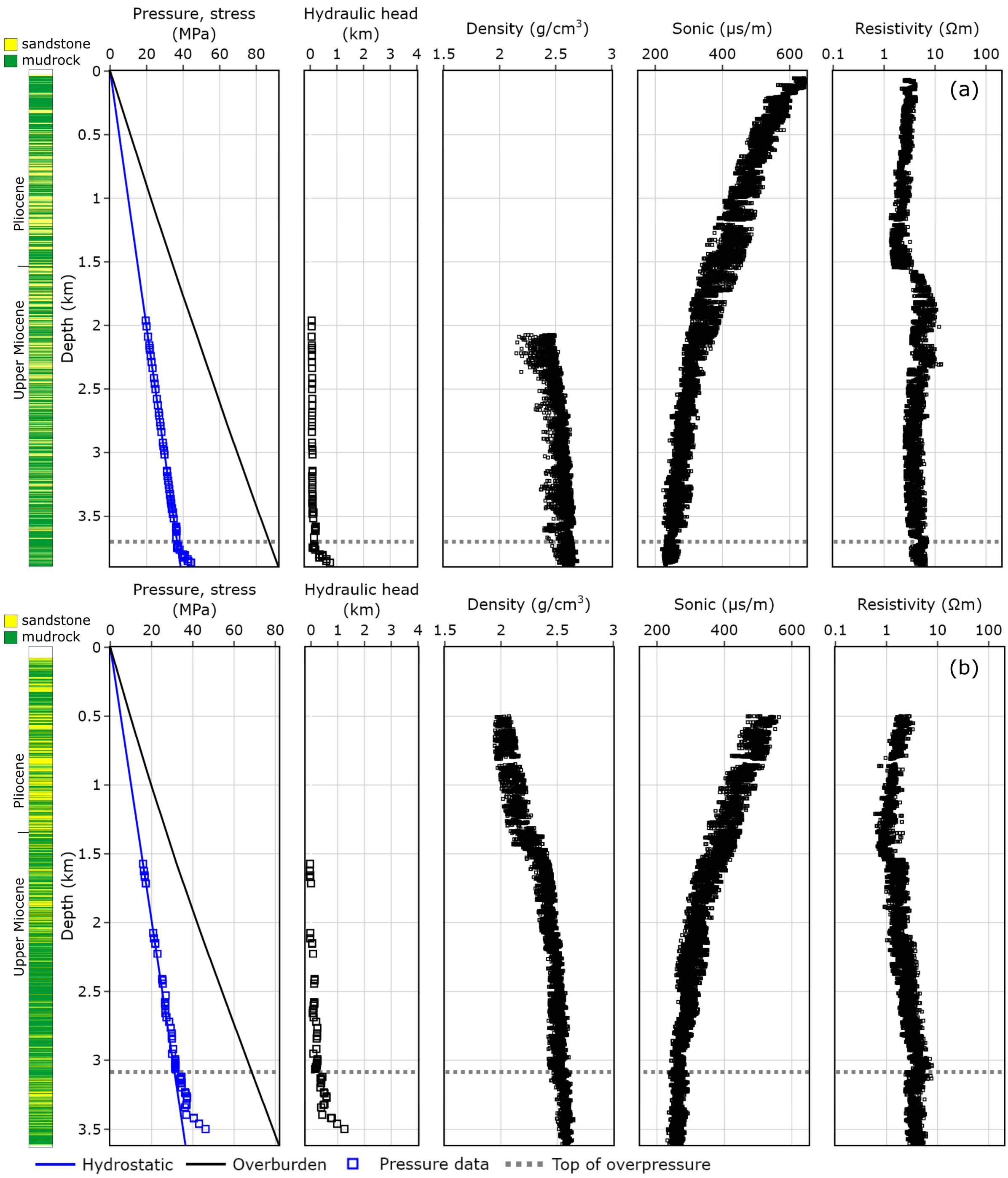


Fig. S4 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 36 and **b** Well no. 10

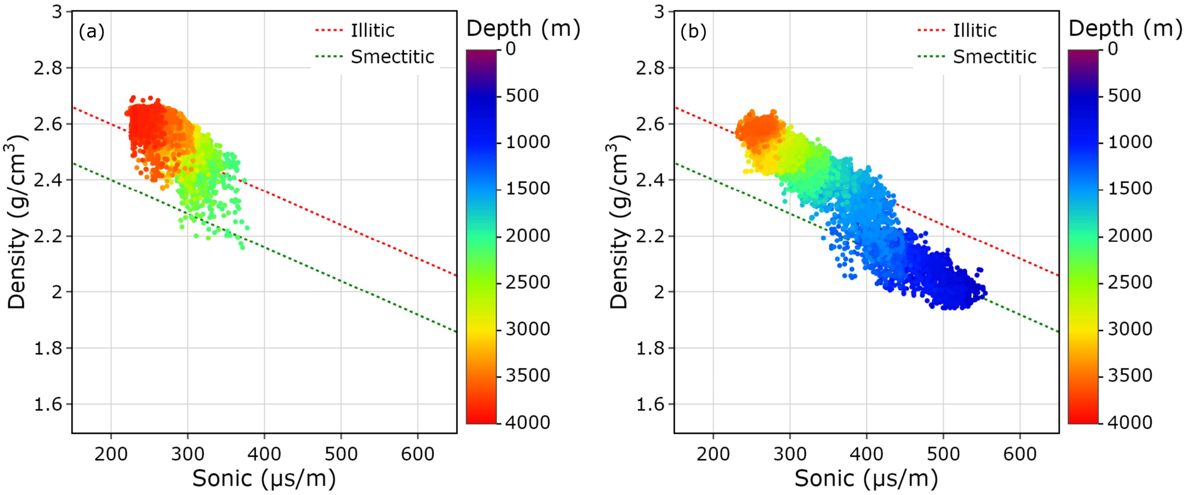


Fig. S5 Sonic-density cross plot of mudrocks at **a** Well no. 36 and **b** Well no. 10

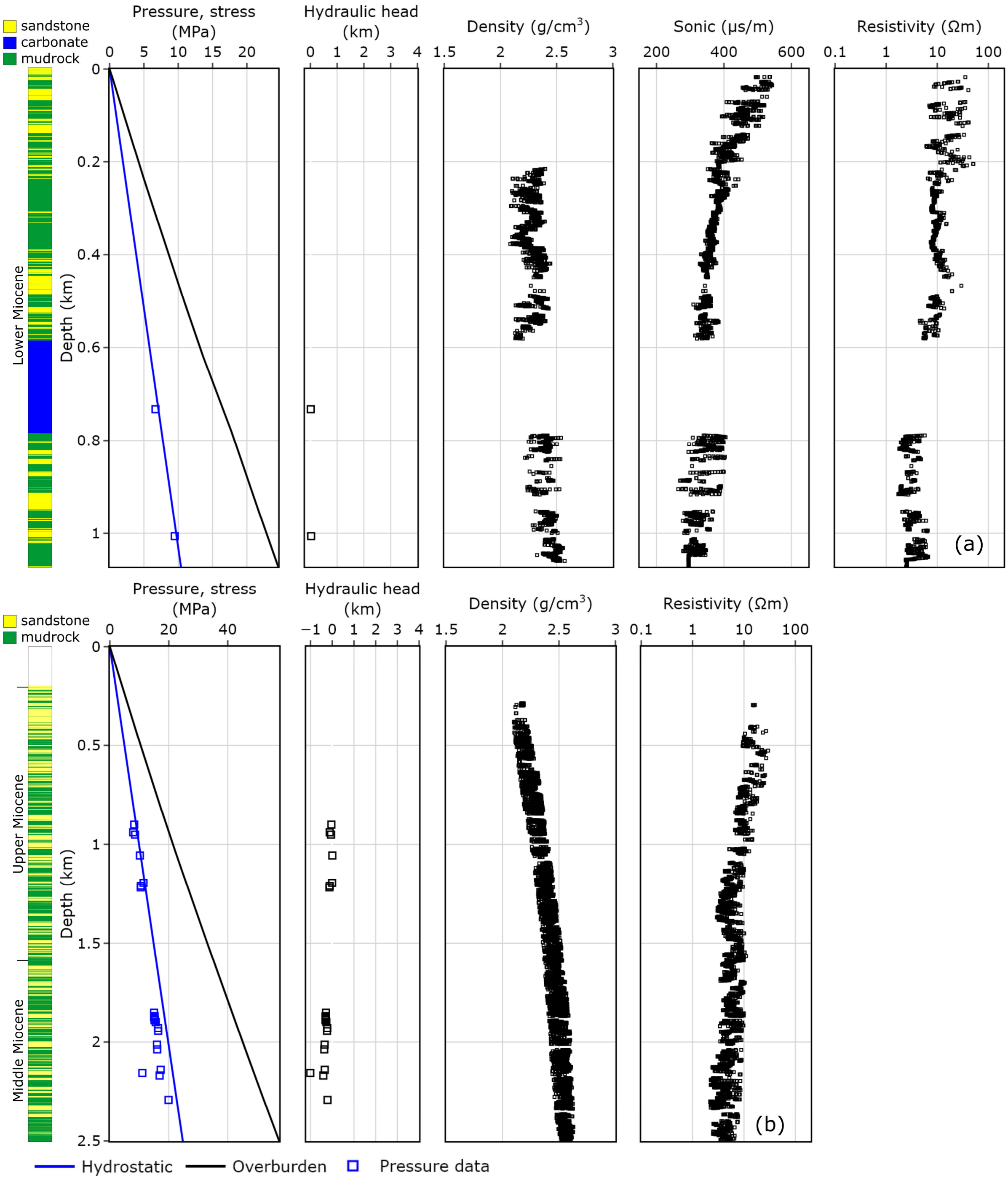


Fig. S6 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 2 and **b** Well no. 14

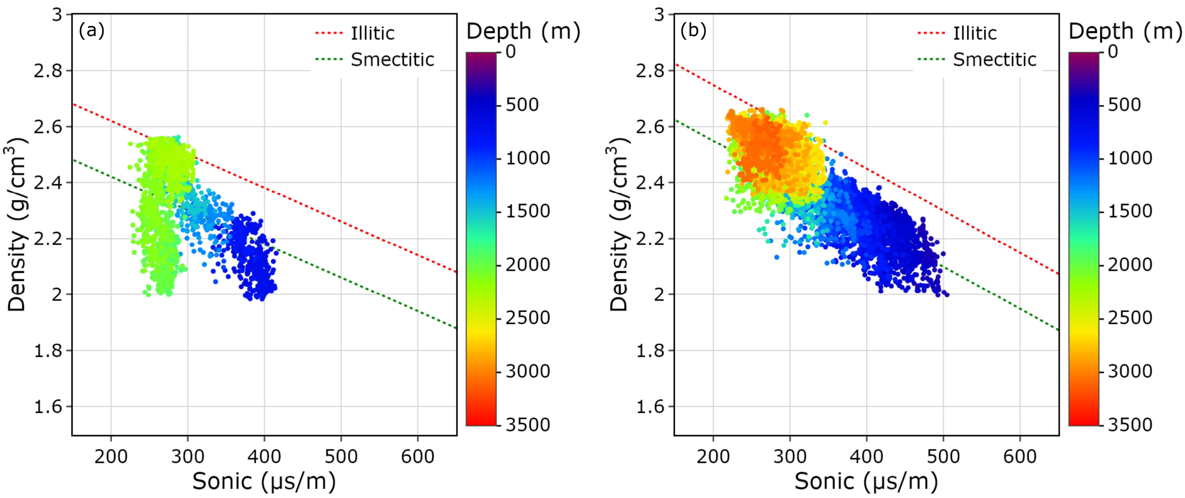


Fig. S7 Sonic-density cross plot of mudrocks at **a** Well no. 3 and **b** Well no. 8

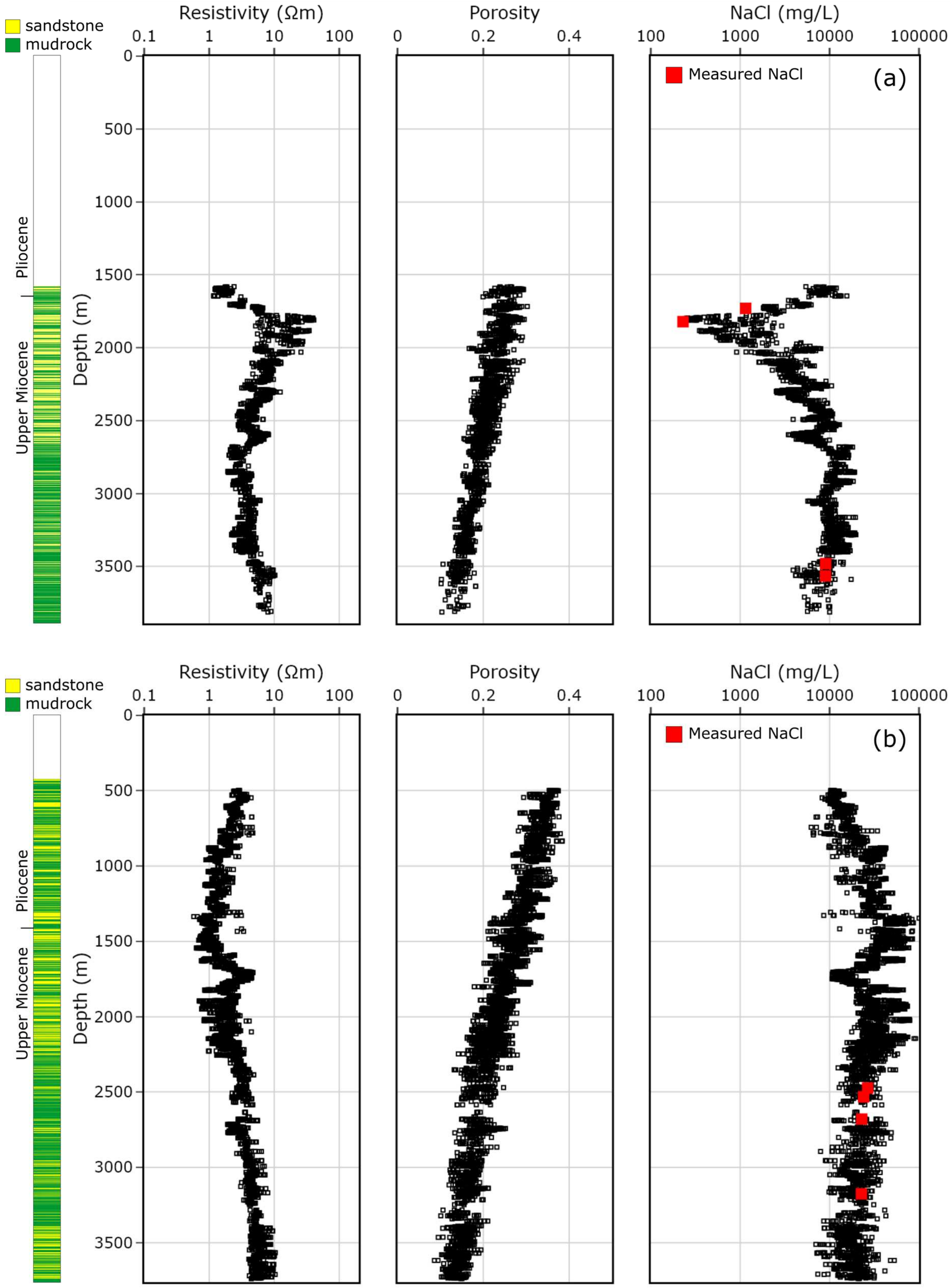


Fig. S8 The result of NaCl estimation at **a** Well no. 23 and **b** Well no. 9

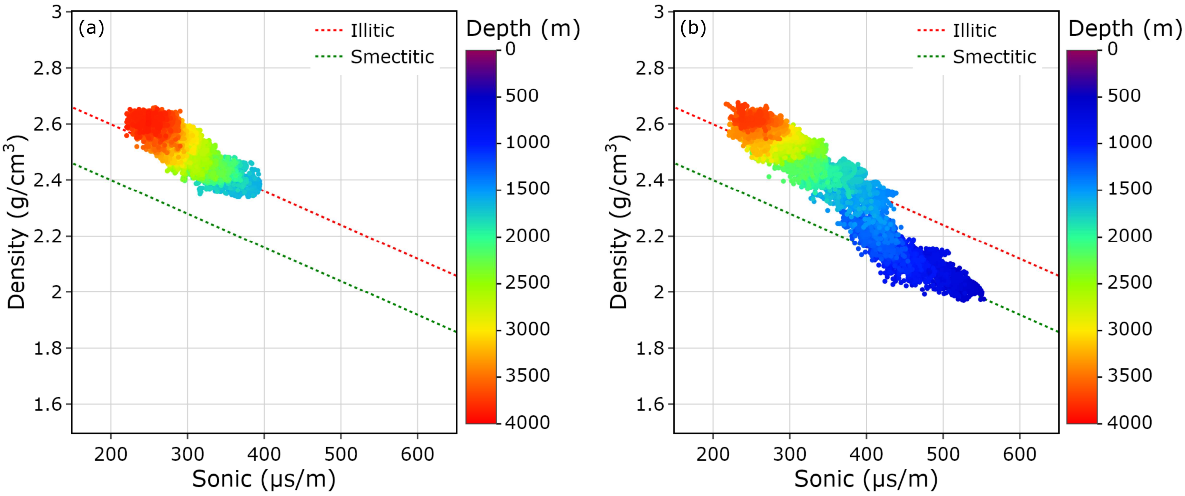


Fig. S9 Sonic-density cross plot of mudrocks at **a** Well no. 23 and **b** Well no. 9

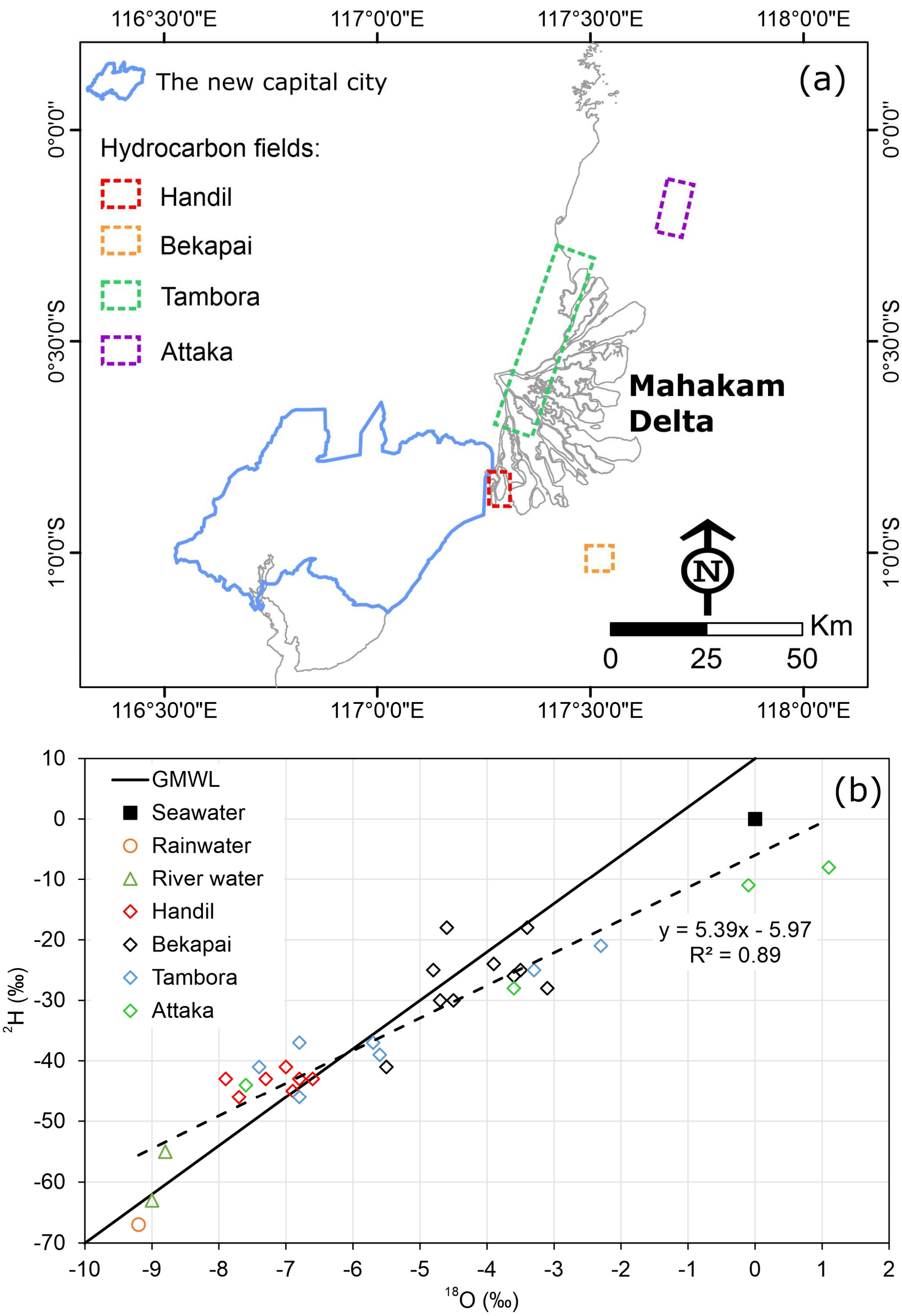


Fig. S10 a Location of some hydrocarbon fields in the Lower Kutai Basin; **b** Stable isotopes of deuterium (^{2}H) and oxygen-18 (^{18}O) from Furlan et al. (1995); GMWL refers to the global meteoric water line

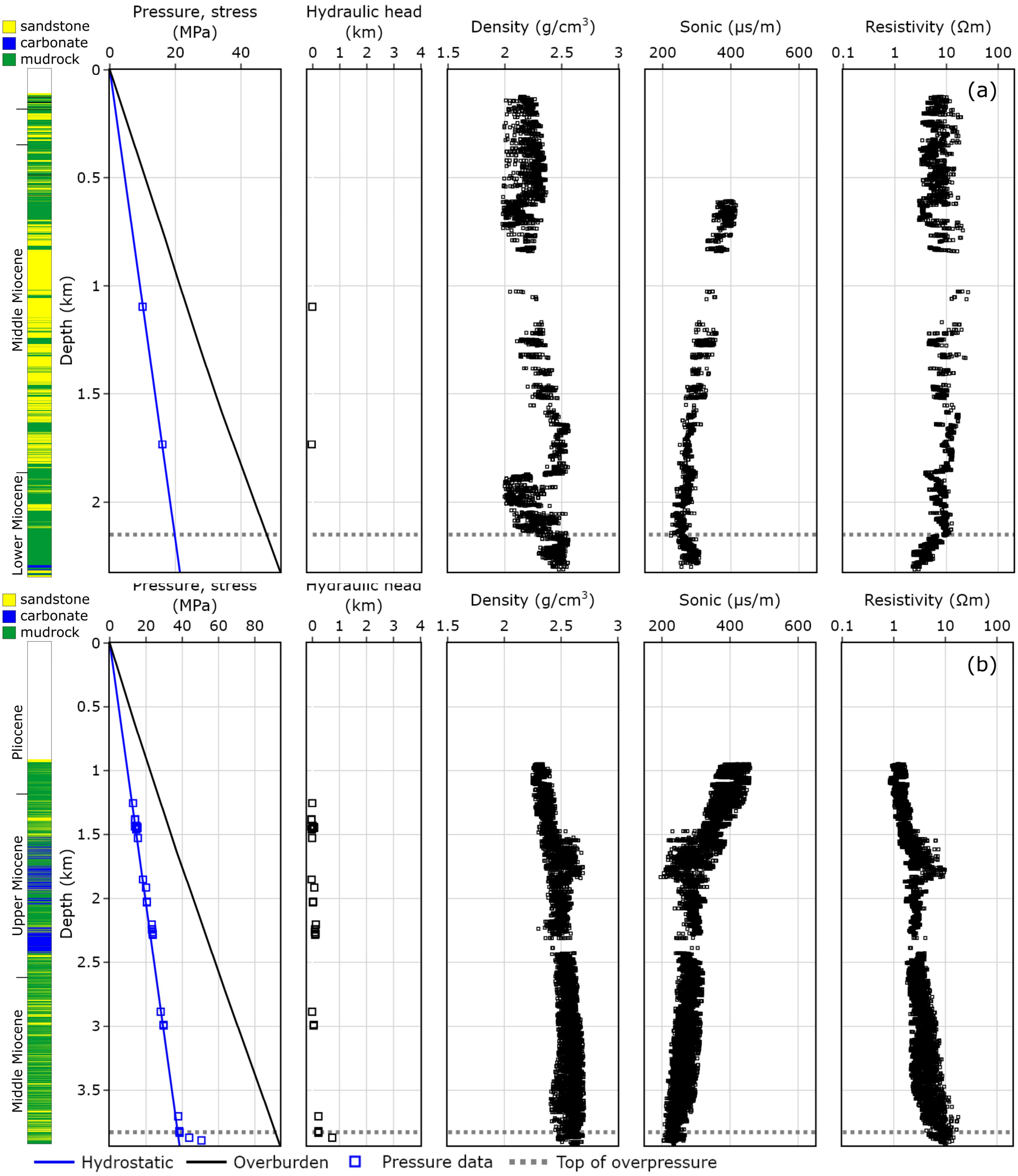


Fig. S11 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 3 and **b** Well no. 4

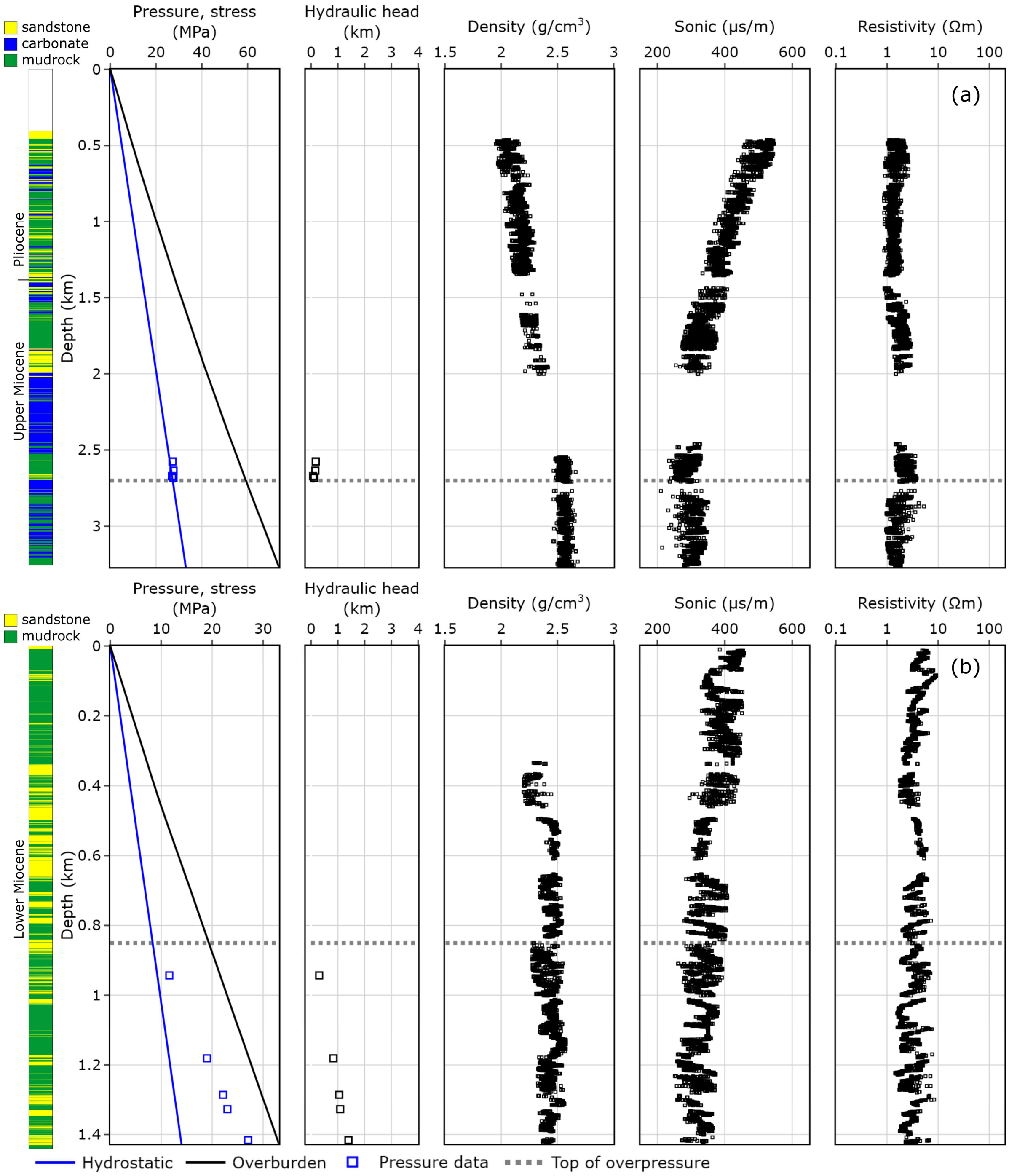


Fig. S12 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 5 and **b** Well no. 7

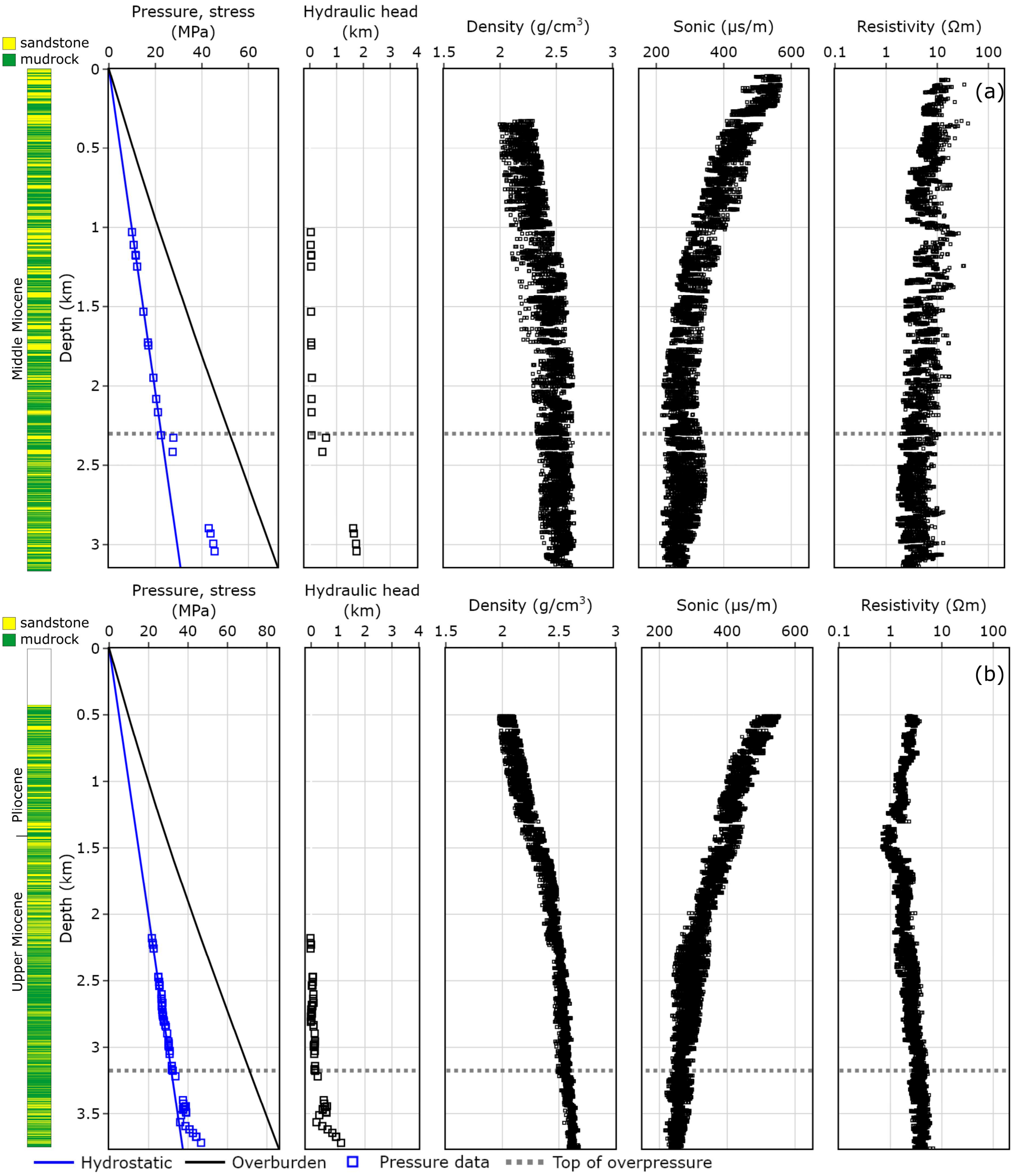


Fig. S13 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 8 and **b** Well no. 9

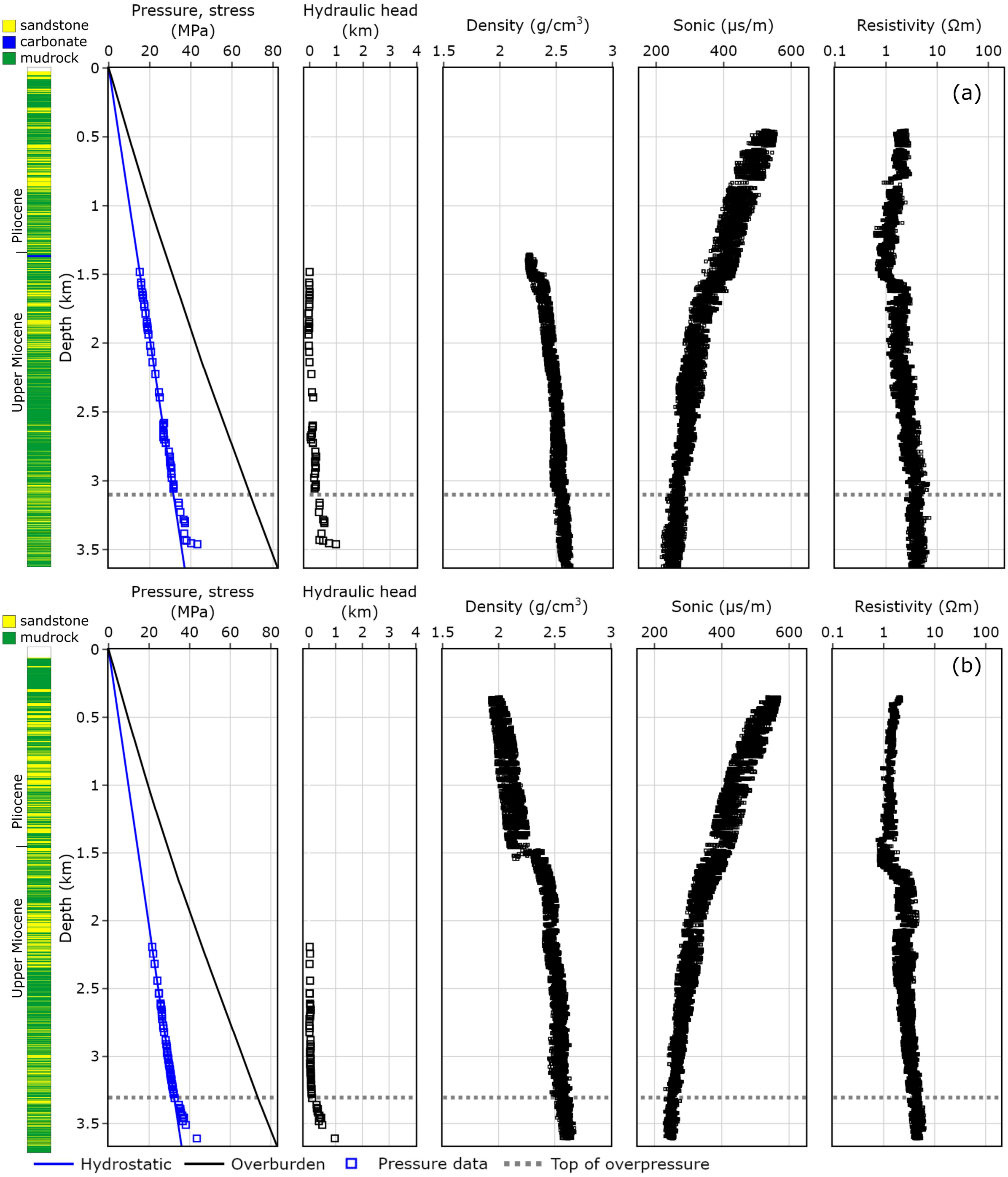


Fig. S14 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 11 and **b** Well no. 12

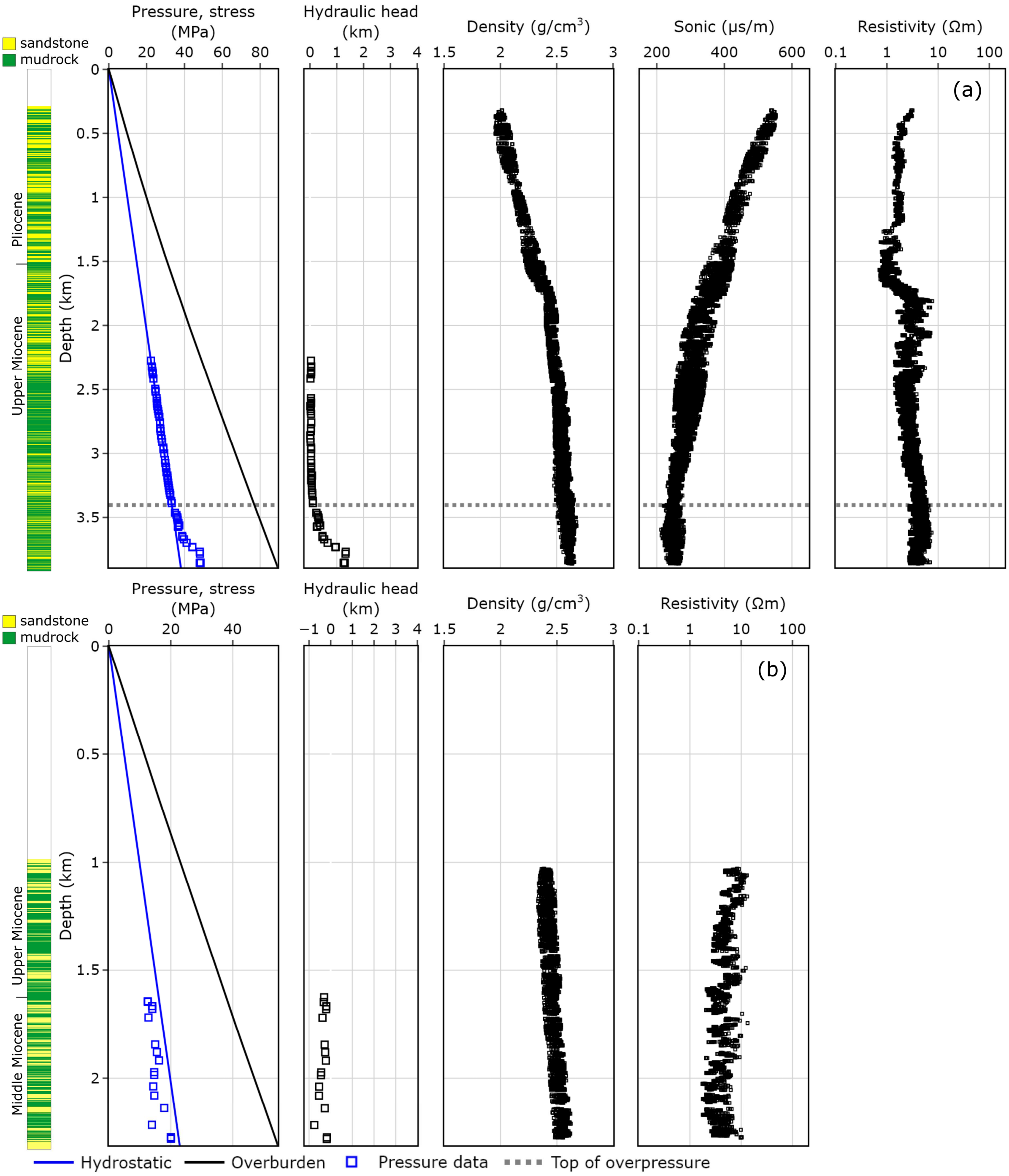


Fig. S15 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 13 and **b** Well no. 15

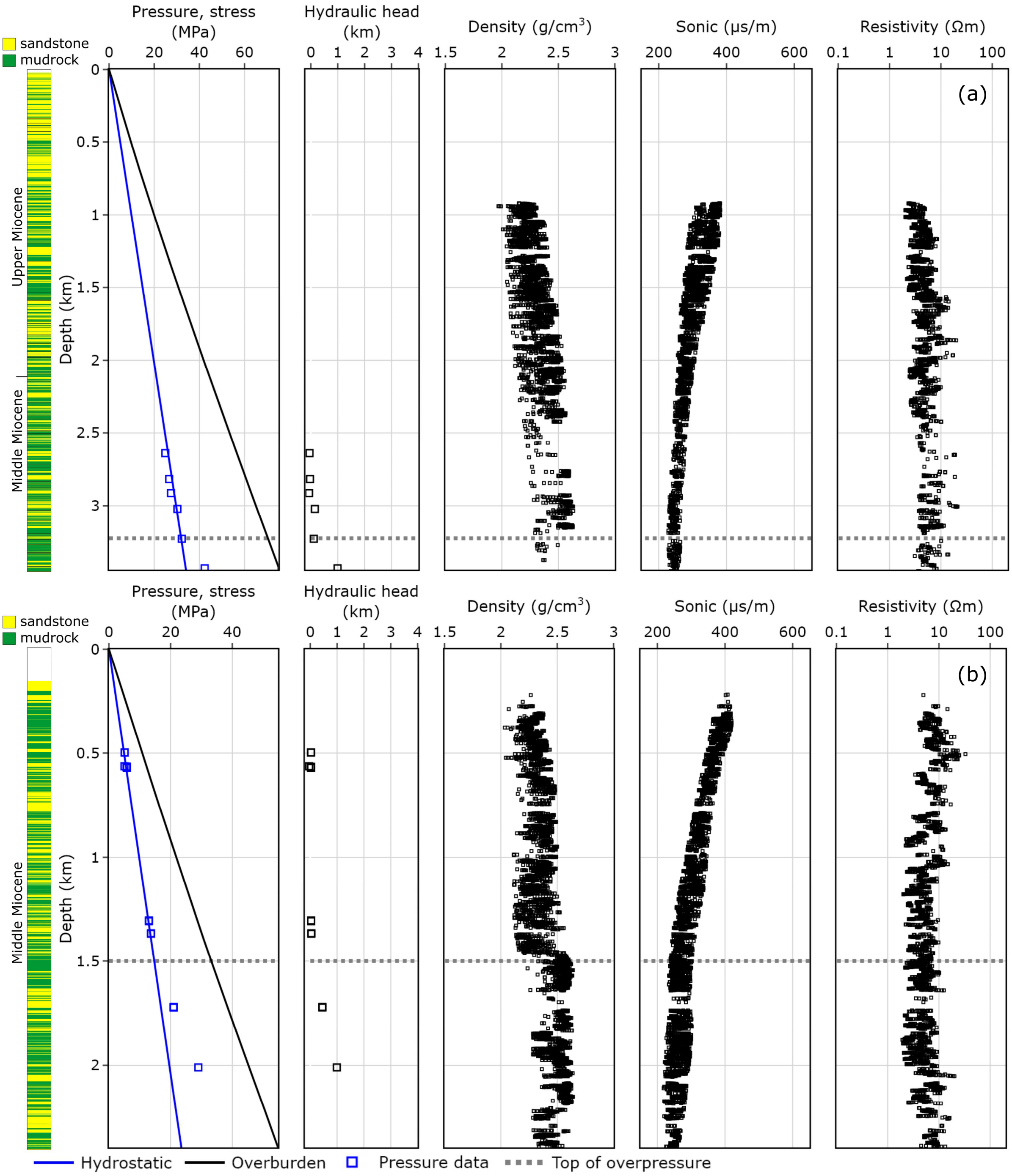


Fig. S16 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 16 and **b** Well no. 17

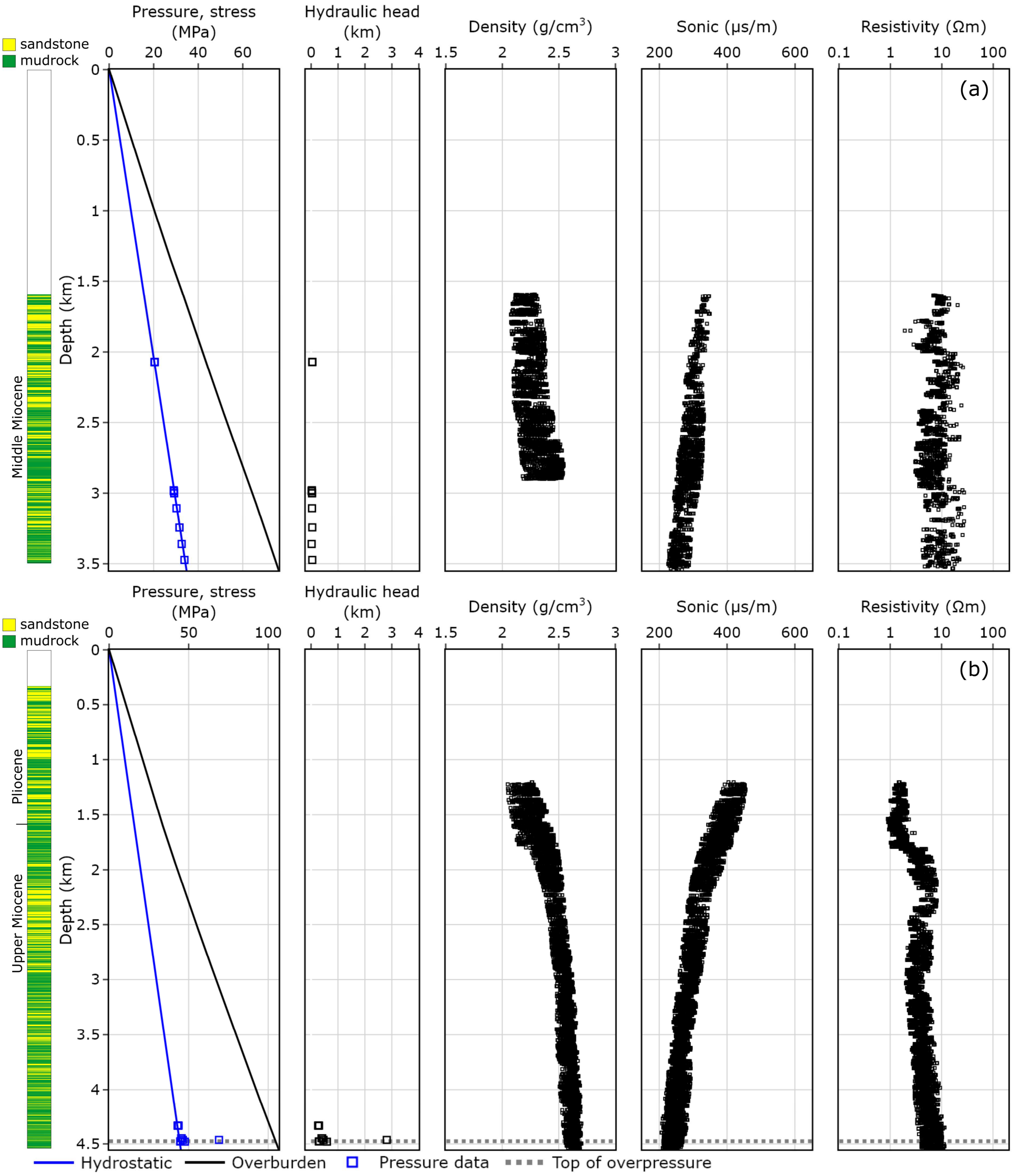


Fig. S17 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 19 and **b** Well no. 20

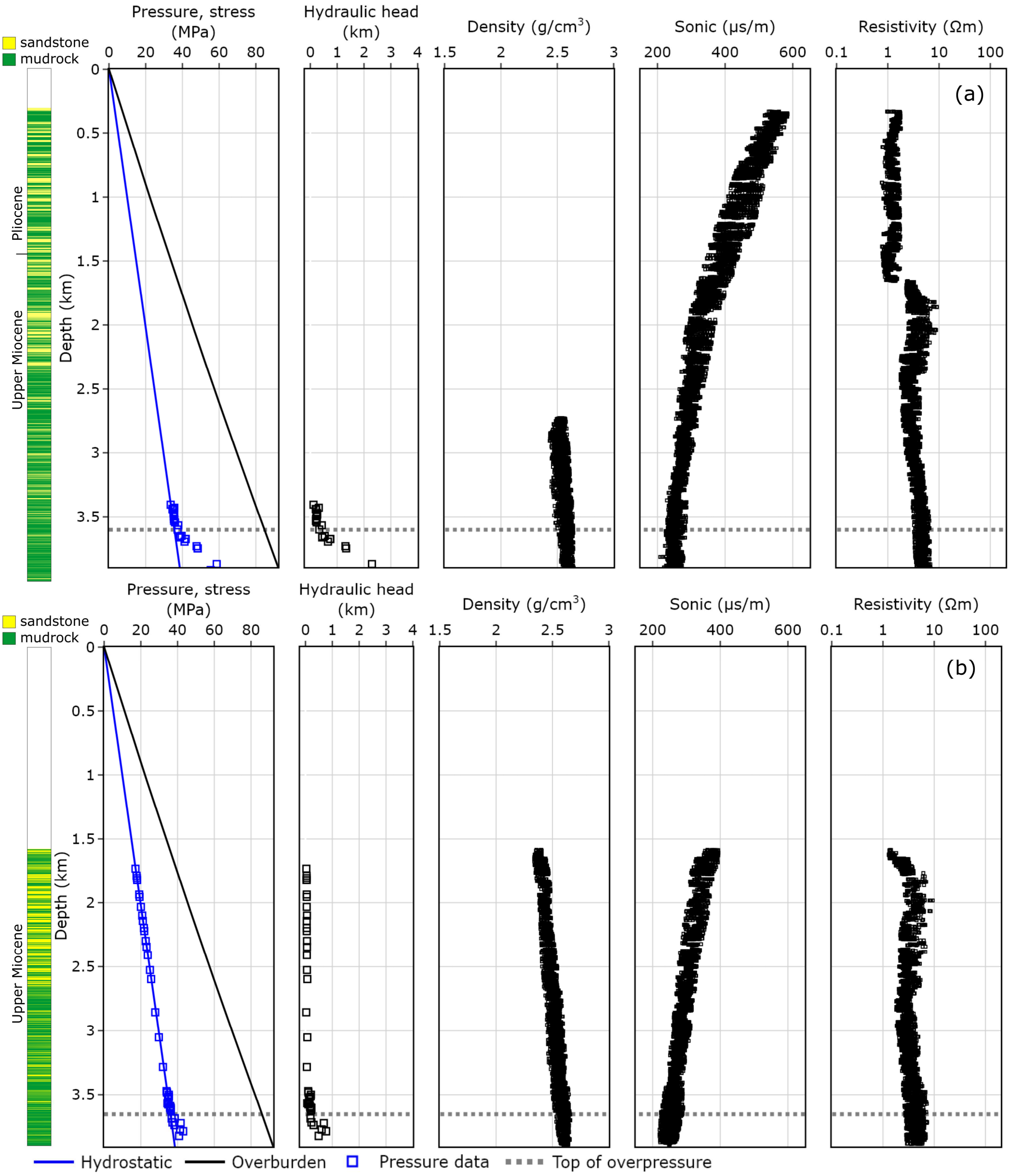


Fig. S18 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 22 and **b** Well no. 23

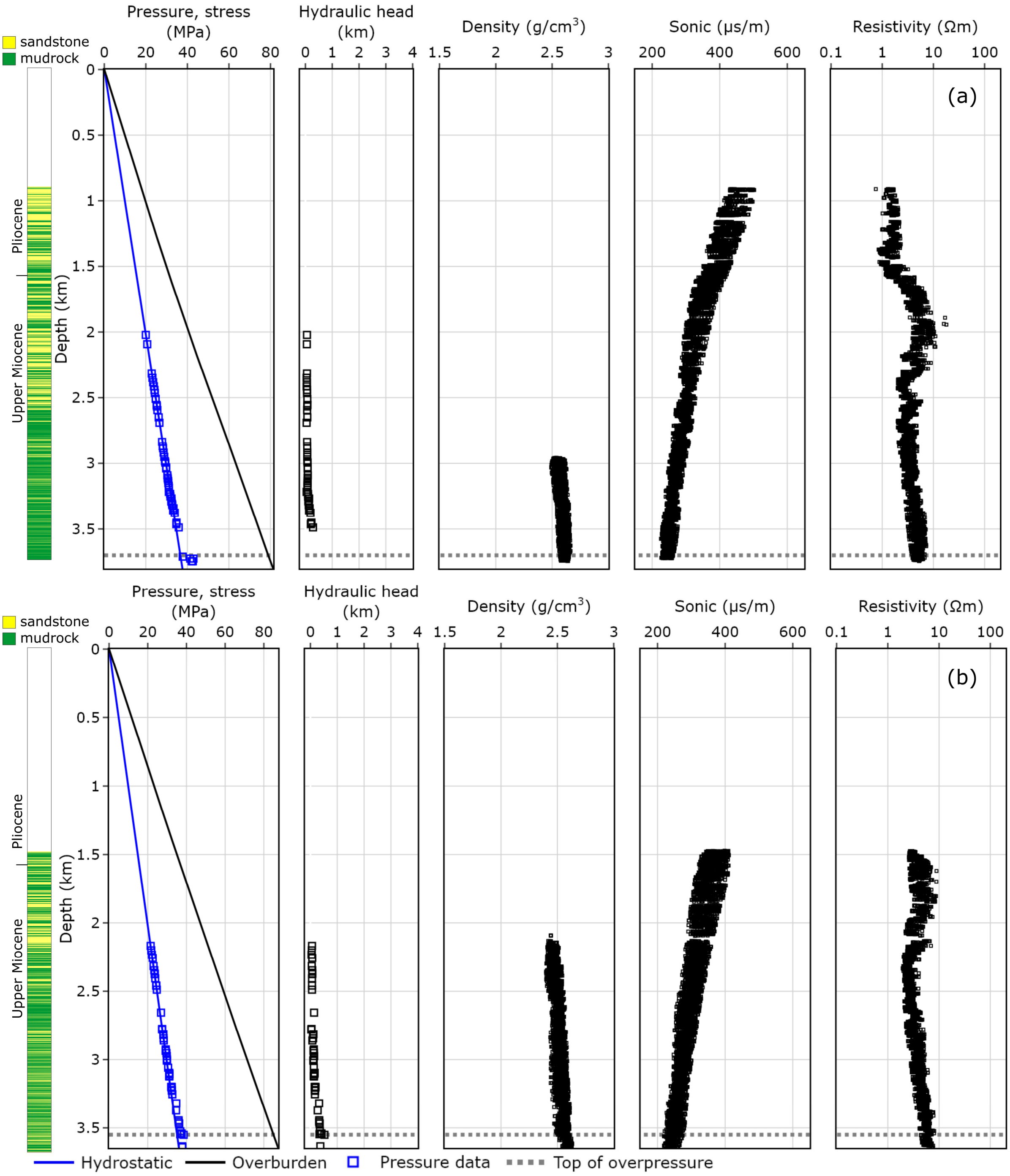


Fig. S19 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 24 and **b** Well no. 25

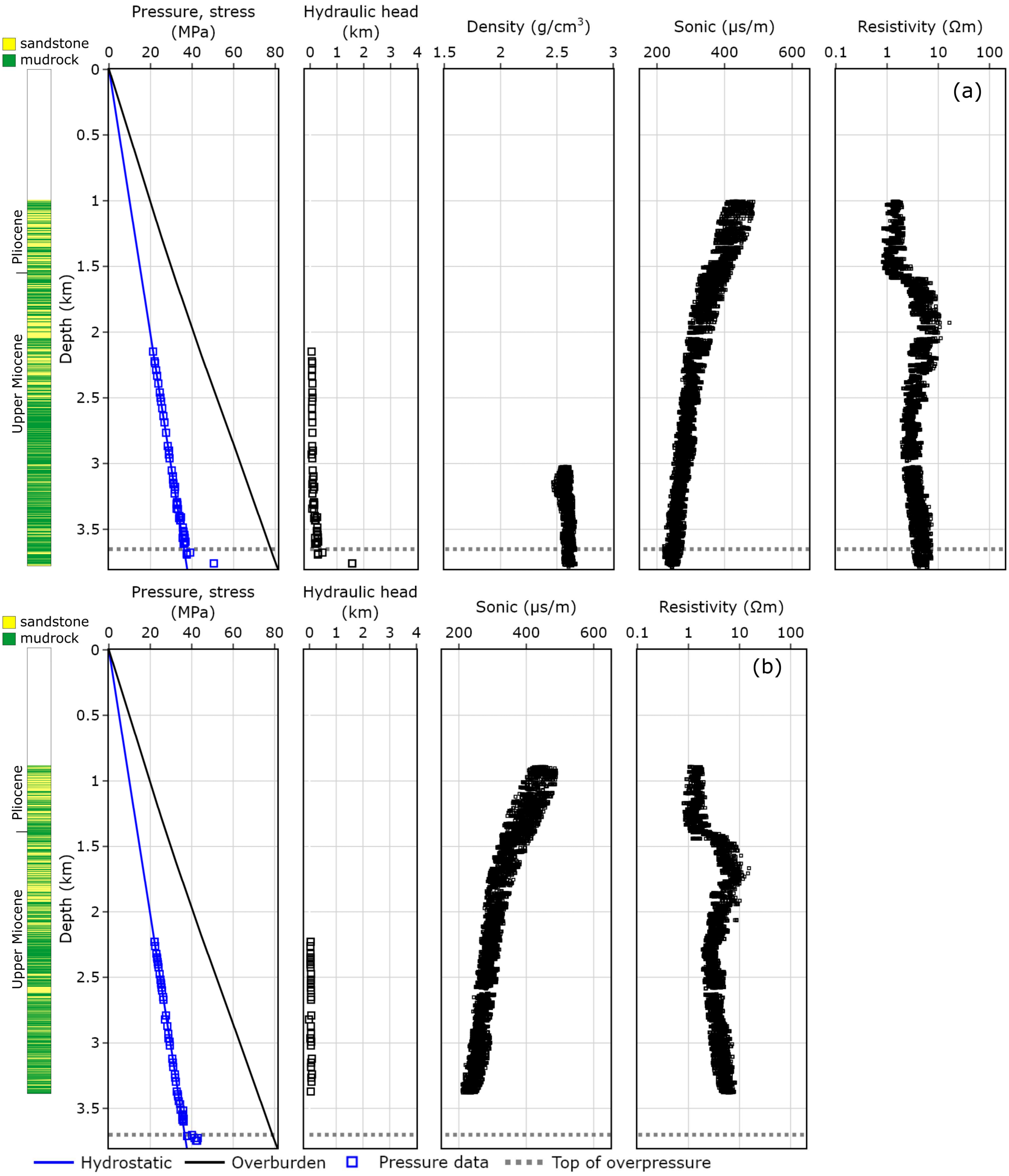


Fig. S20 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 26 and **b** Well no. 27

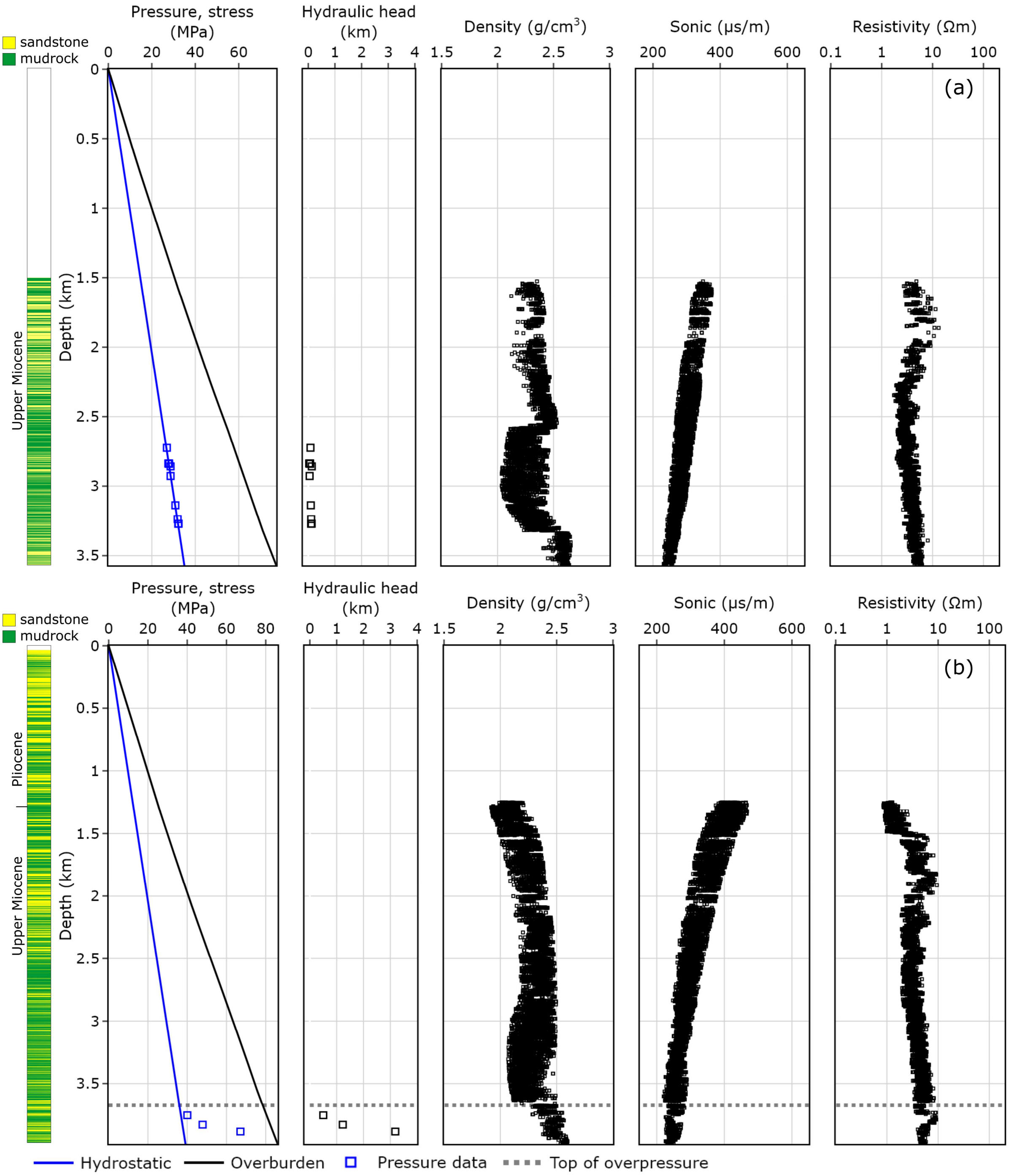


Fig. S21 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 28 and **b** Well no. 29

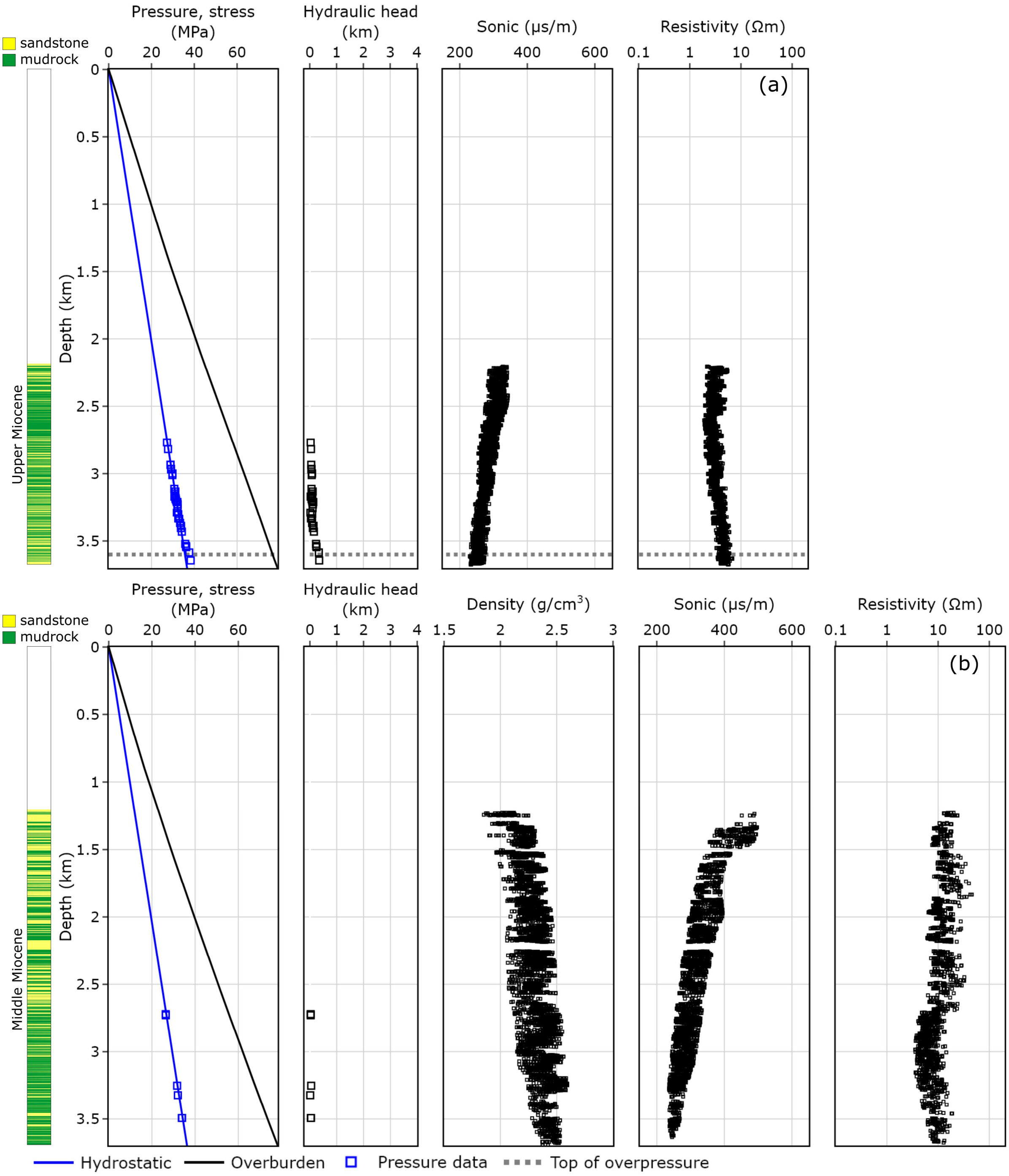


Fig. S22 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 30 and **b** Well no. 31

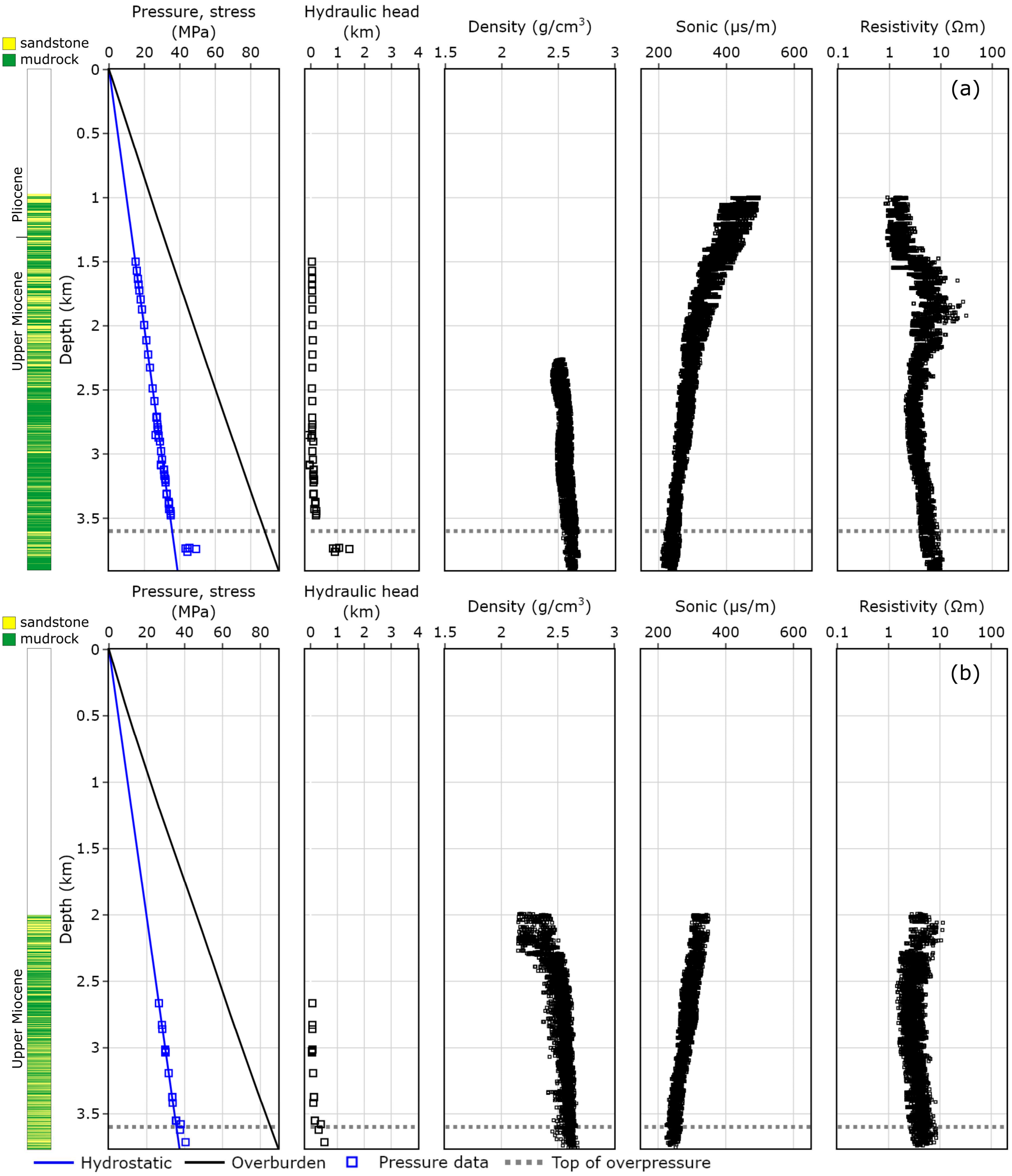


Fig. S23 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 32 and **b** Well no. 33

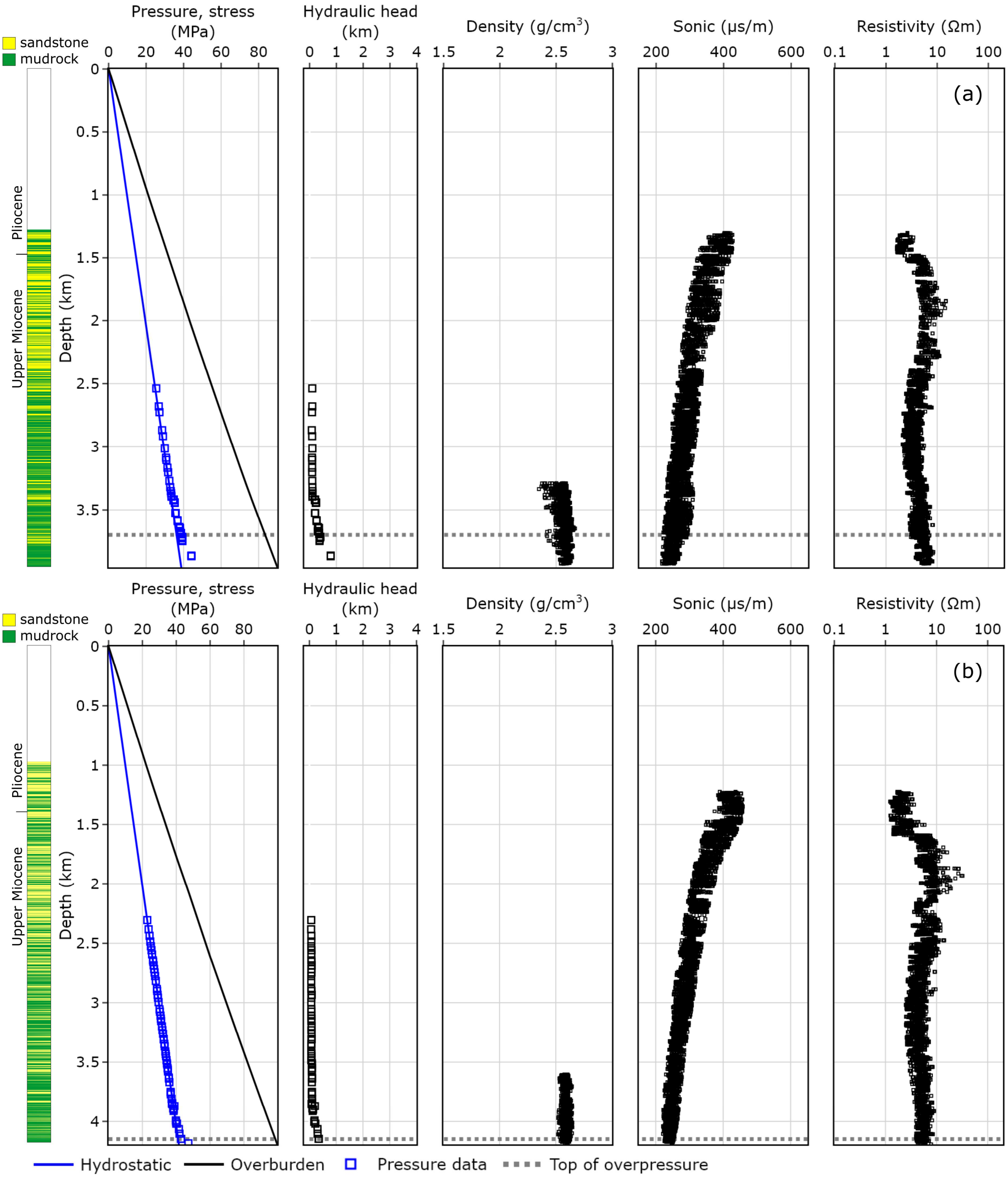


Fig. S24 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 34 and **b** Well no. 35

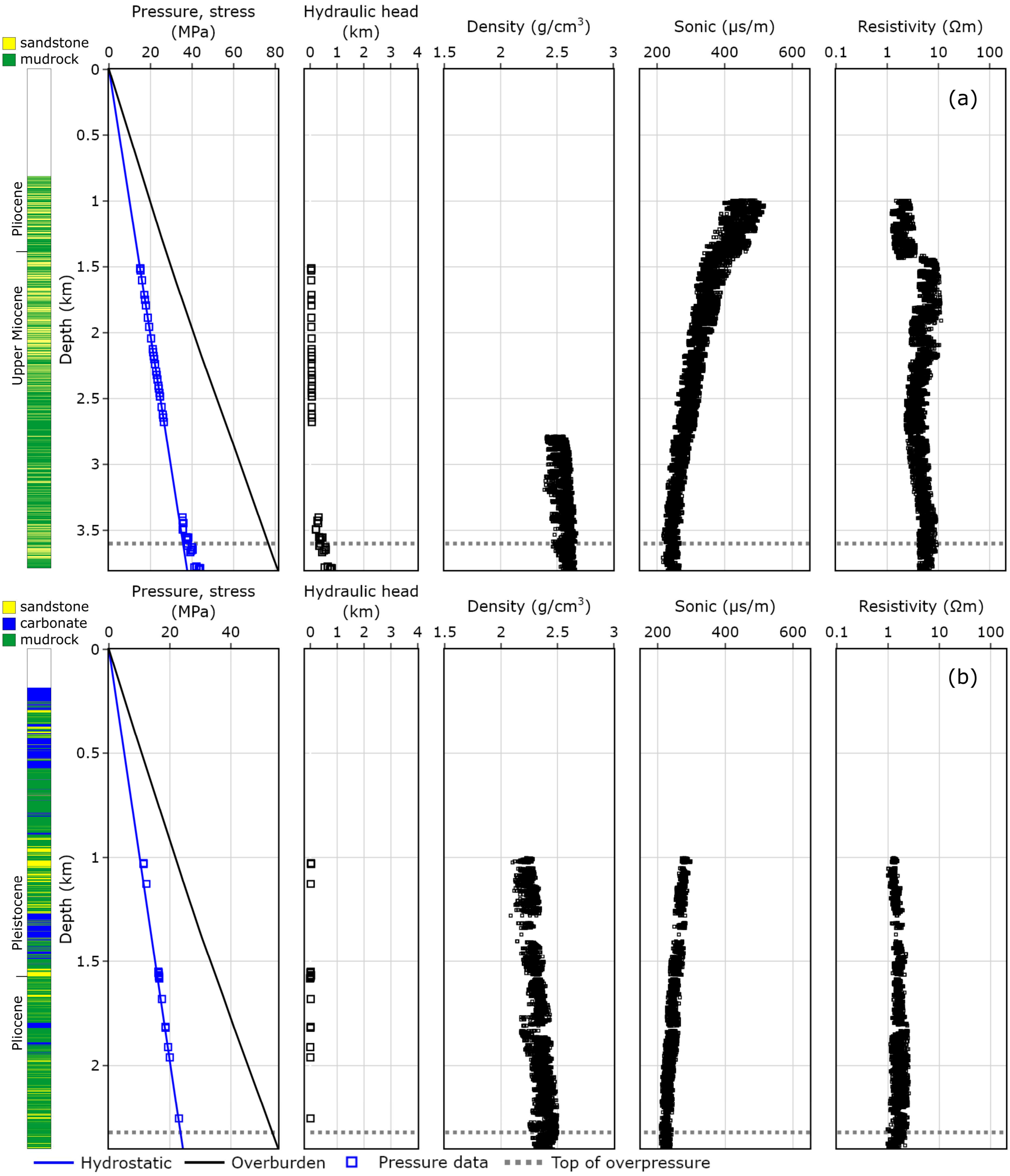


Fig. S25 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 37 and **b** Well no. 38

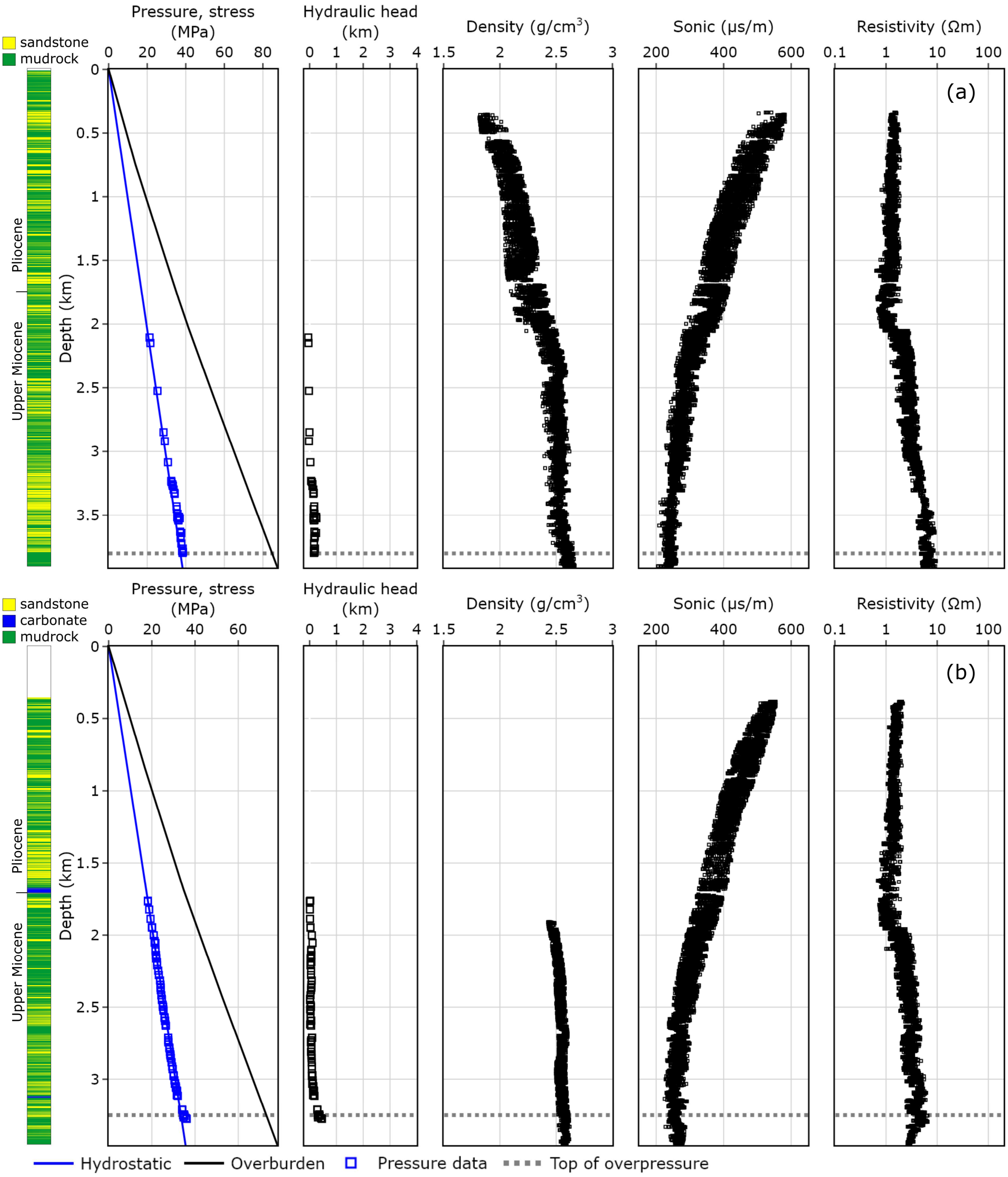


Fig. S26 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 39 and **b** Well no. 40

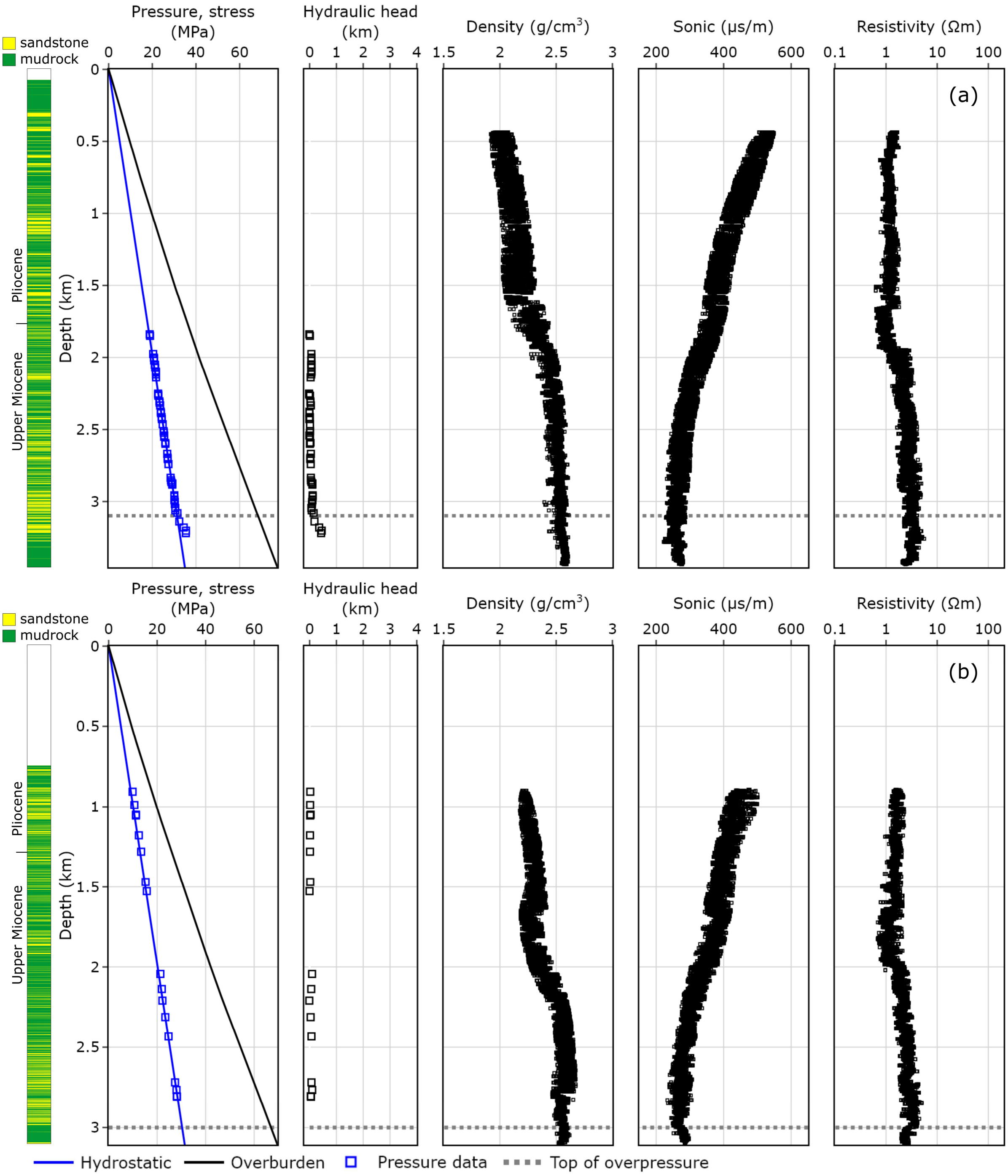


Fig. S27 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 41 and **b** Well no. 42

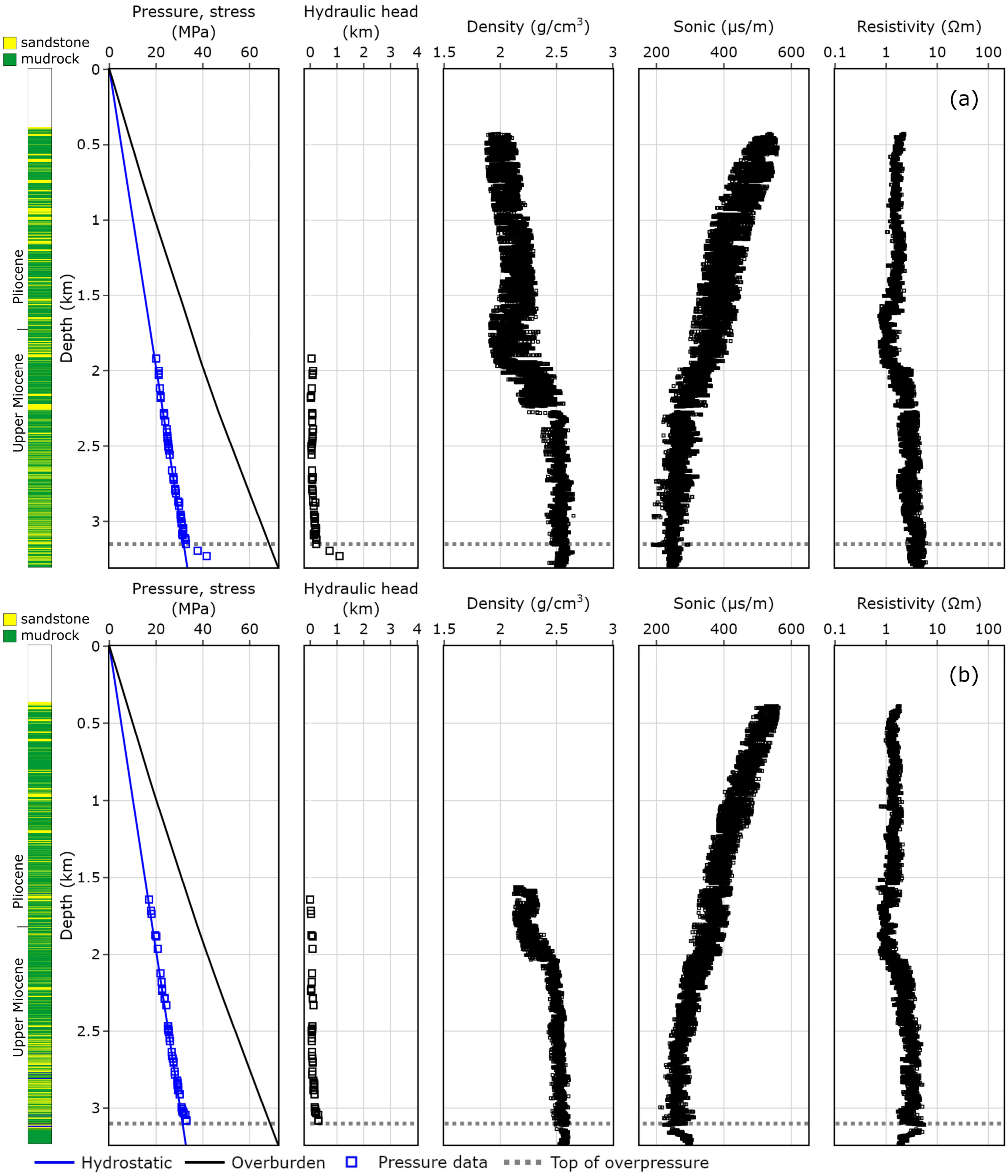


Fig. S28 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at **a** Well no. 43 and **b** Well no. 44

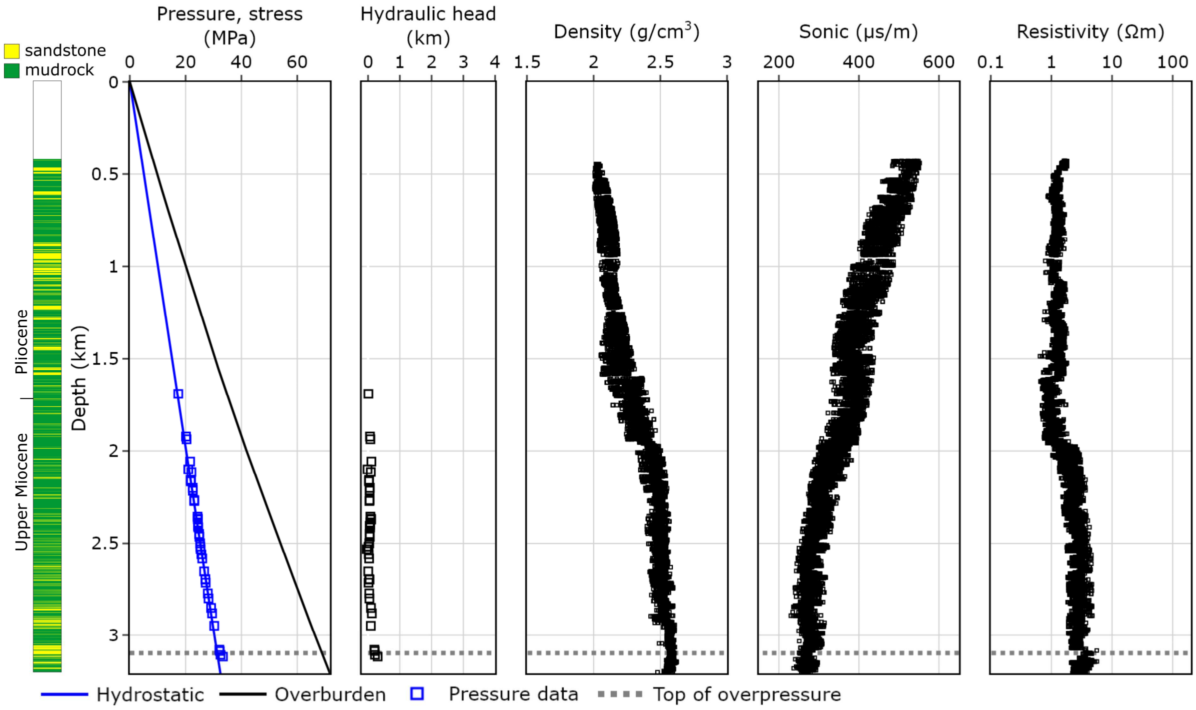


Fig. S29 Lithology, pressure-stress depth plot, computed hydraulic head and wireline logs in mudrocks at Well no. 45

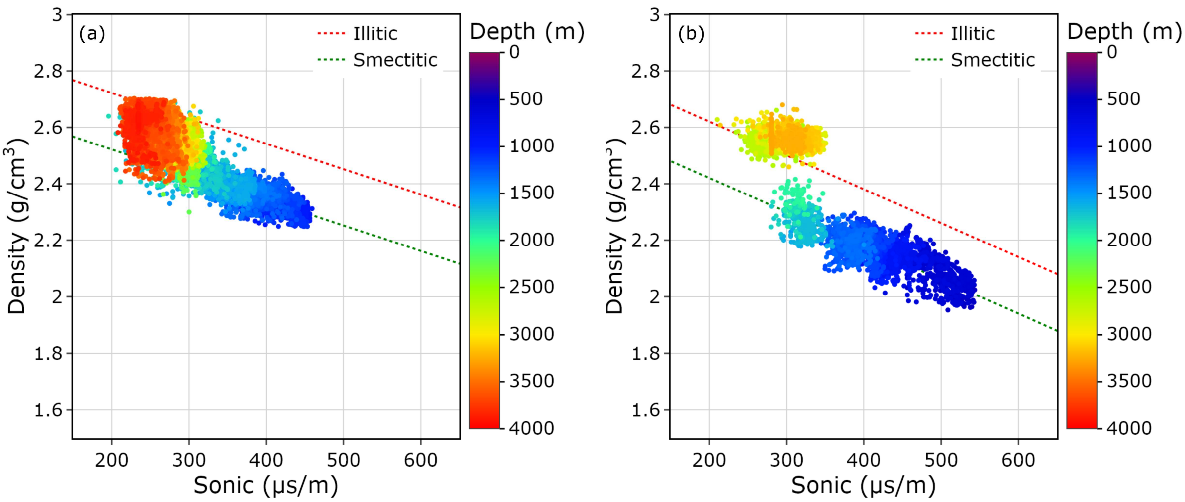


Fig. S30 Sonic-density cross plot of mudrocks at **a** Well no. 4 and **b** Well no. 5

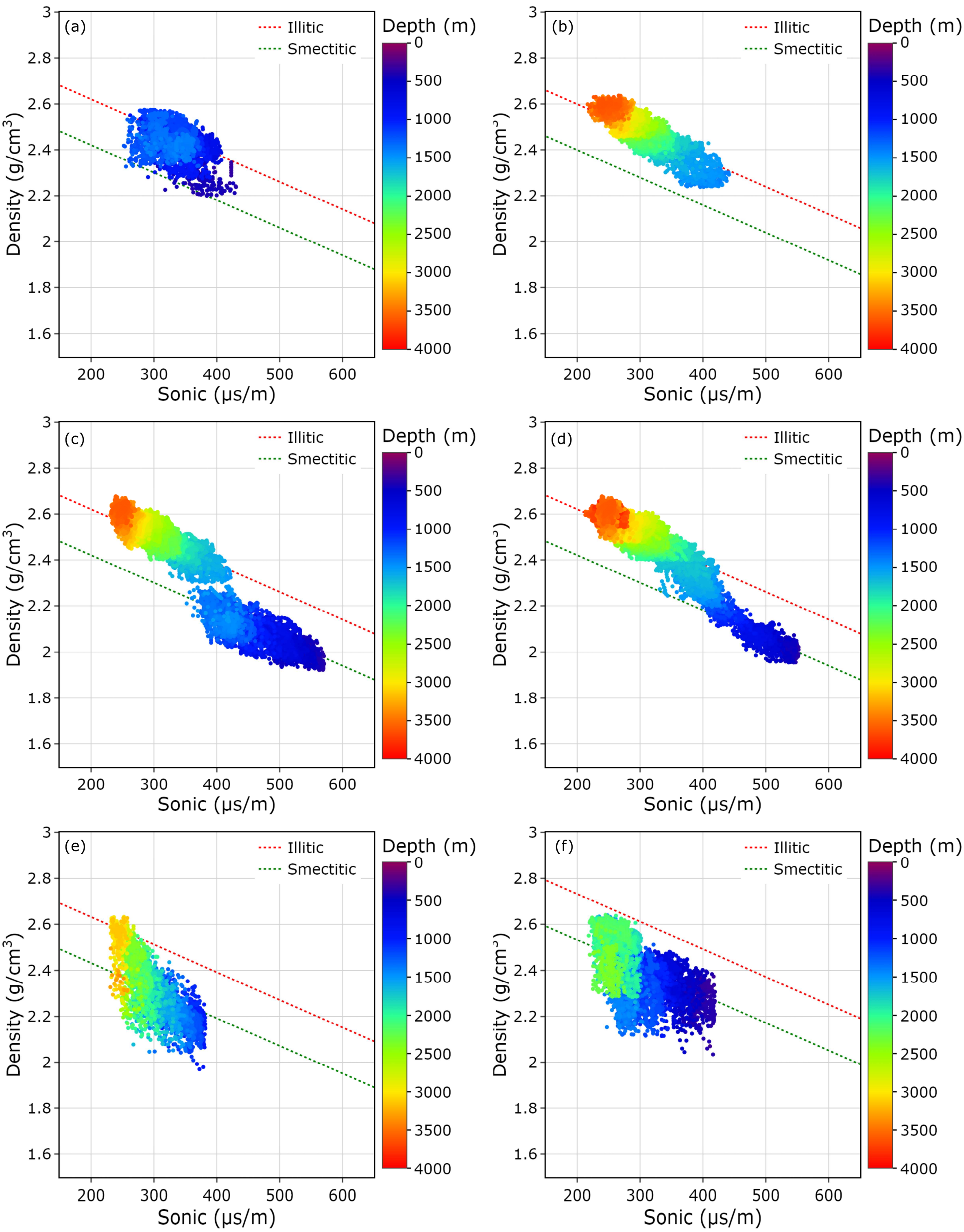


Fig. S31 Sonic-density cross plot of mudrocks at **a** Well no. 7, **b** Well no. 11, **c** Well no. 12, **d** Well no. 13, **e** Well no. 16, and **f** Well no. 17

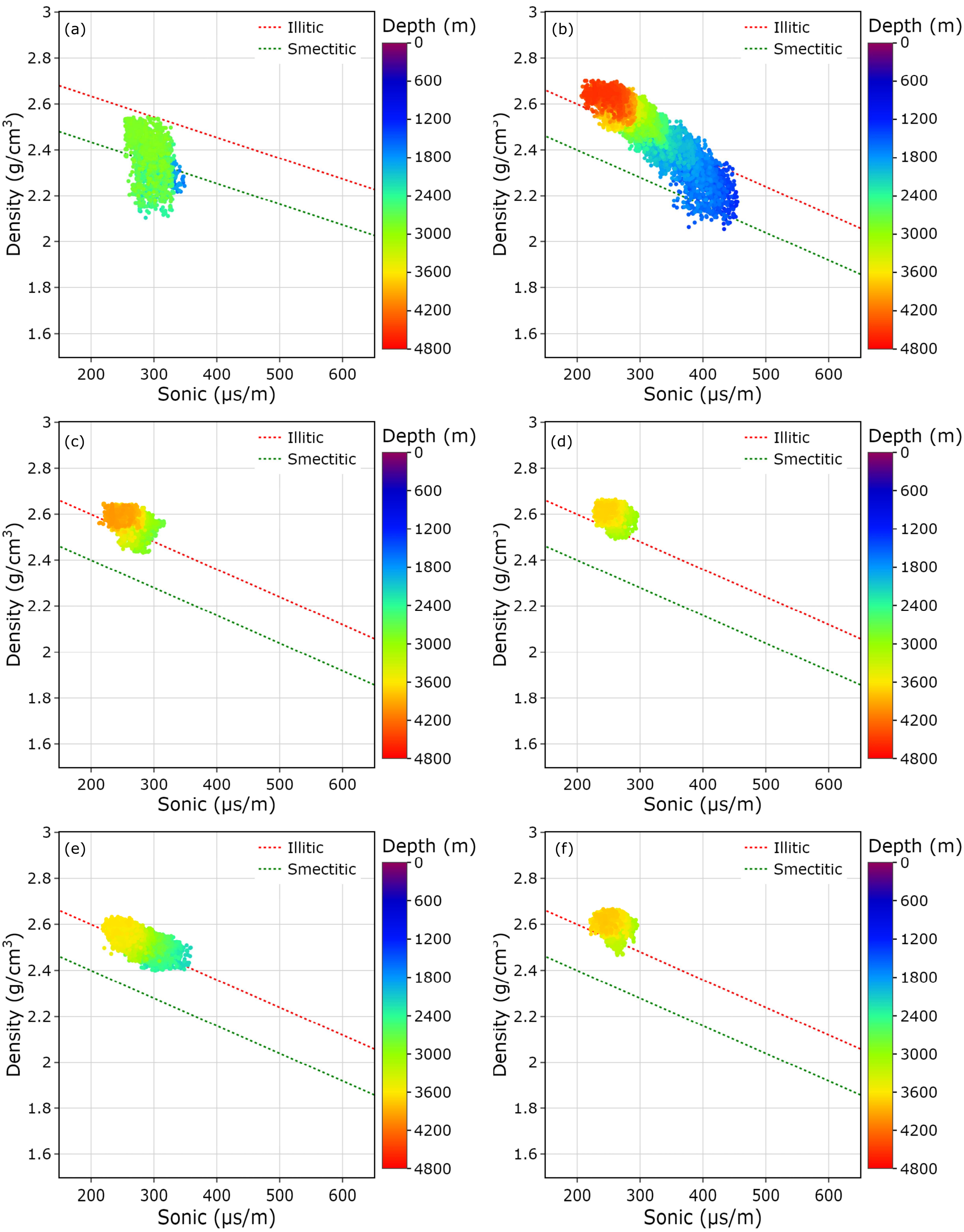


Fig. S32 Sonic-density cross plot of mudrocks at **a** Well no. 19, **b** Well no. 20, **c** Well no. 22, **d** Well no. 24, **e** Well no. 25, and **f** Well no. 26

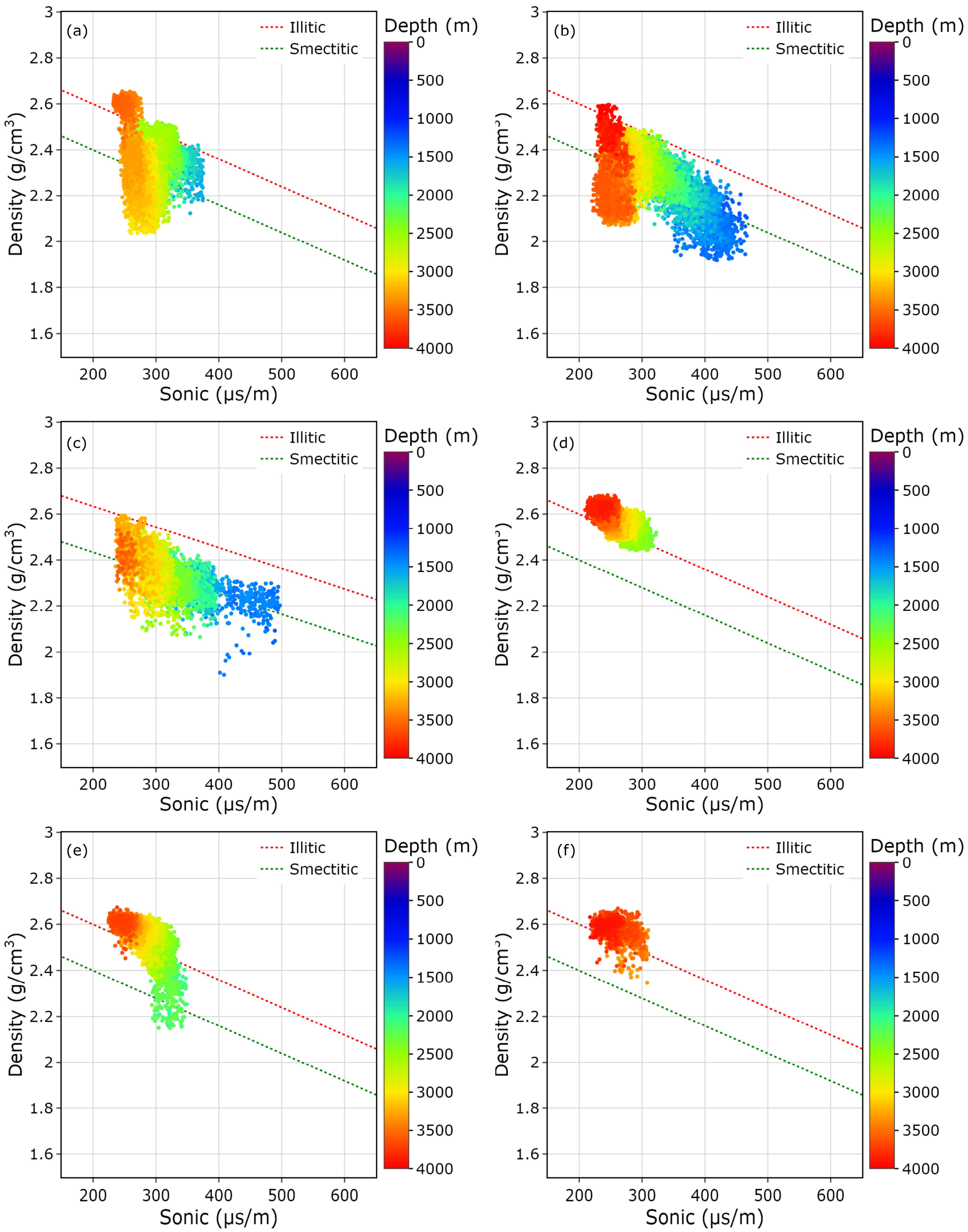


Fig. S33 Sonic-density cross plot of mudrocks at **a** Well no. 28, **b** Well no. 29, **c** Well no. 31, **d** Well no. 32, **e** Well no. 33, and **f** Well no. 34

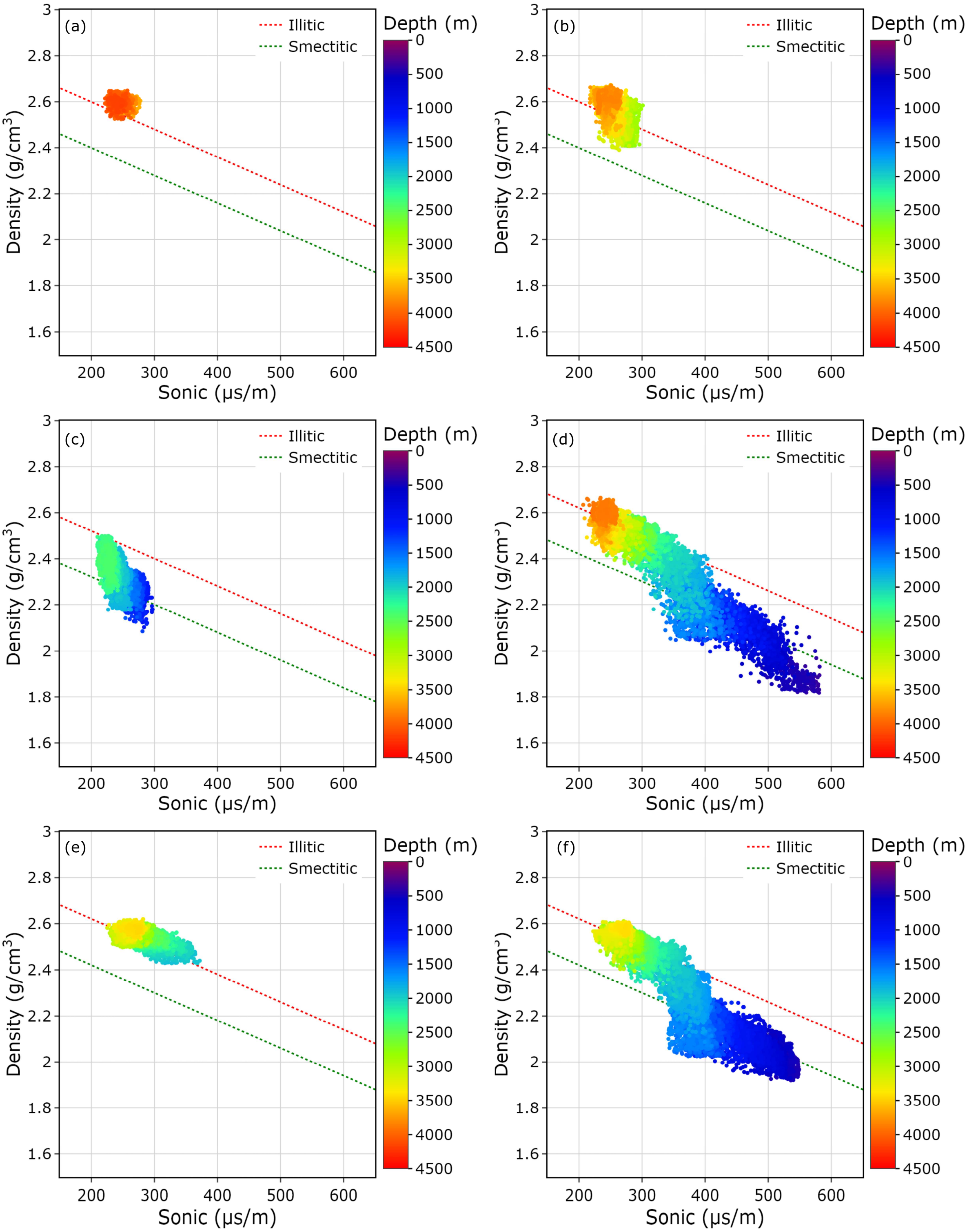


Fig. S34 Sonic-density cross plot of mudrocks at **a** Well no. 35, **b** Well no. 37, **c** Well no. 38, **d** Well no. 39, **e** Well no. 40, and **f** Well no. 41

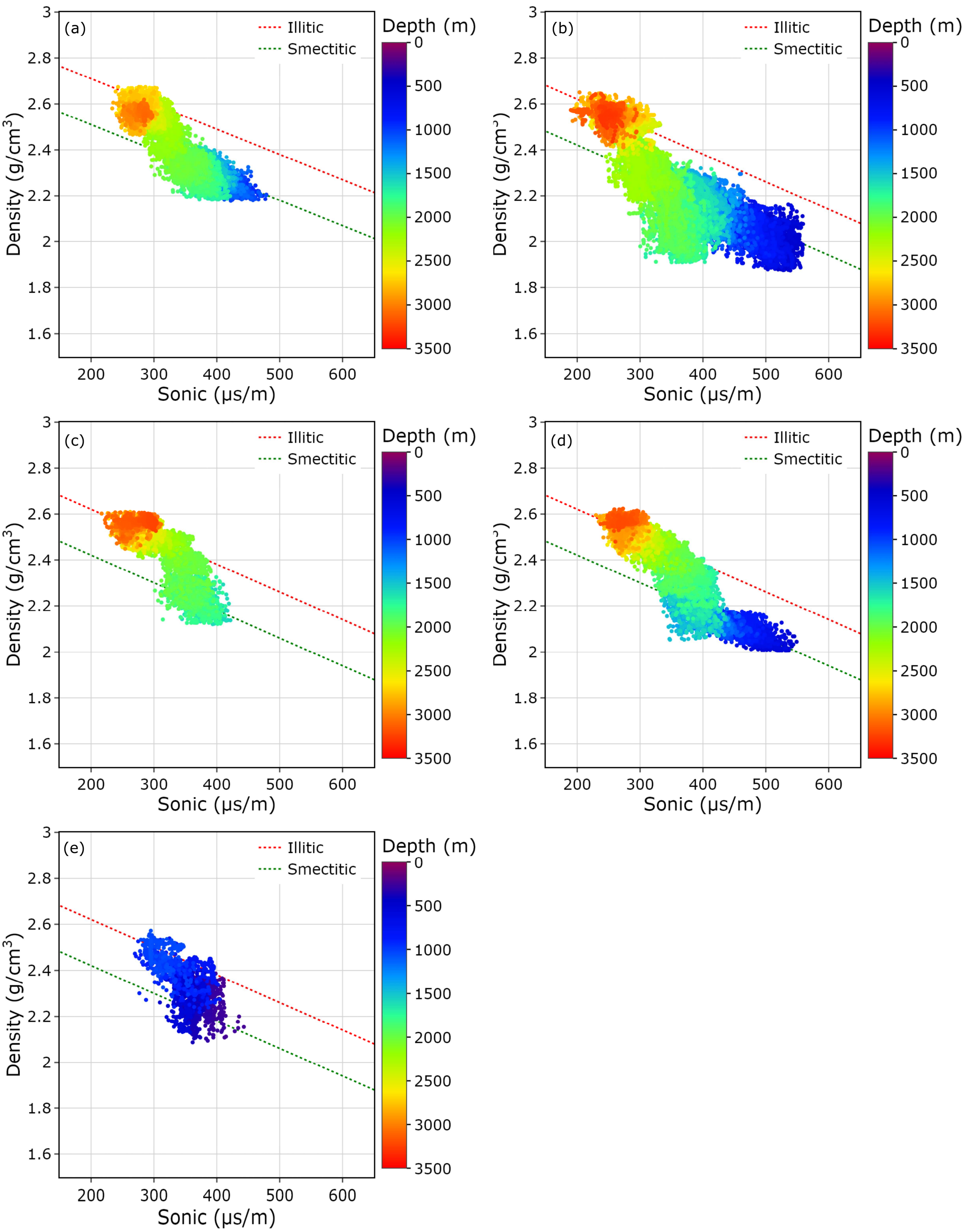


Fig. S35 Sonic-density cross plot of mudrocks at **a** Well no. 42, **b** Well no. 43, **c** Well no. 44, **d** Well no. 45, and **e** Well no. 2

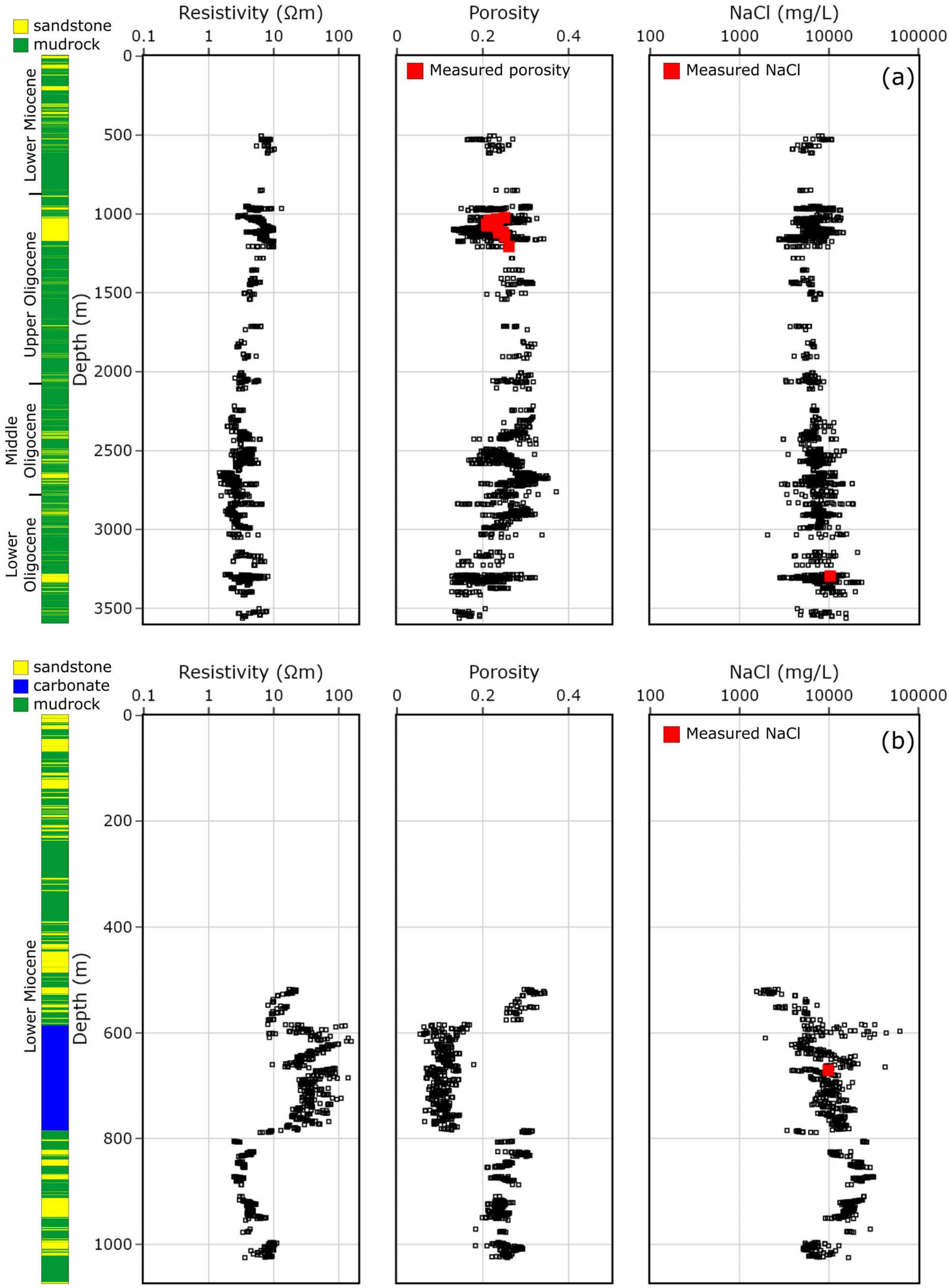
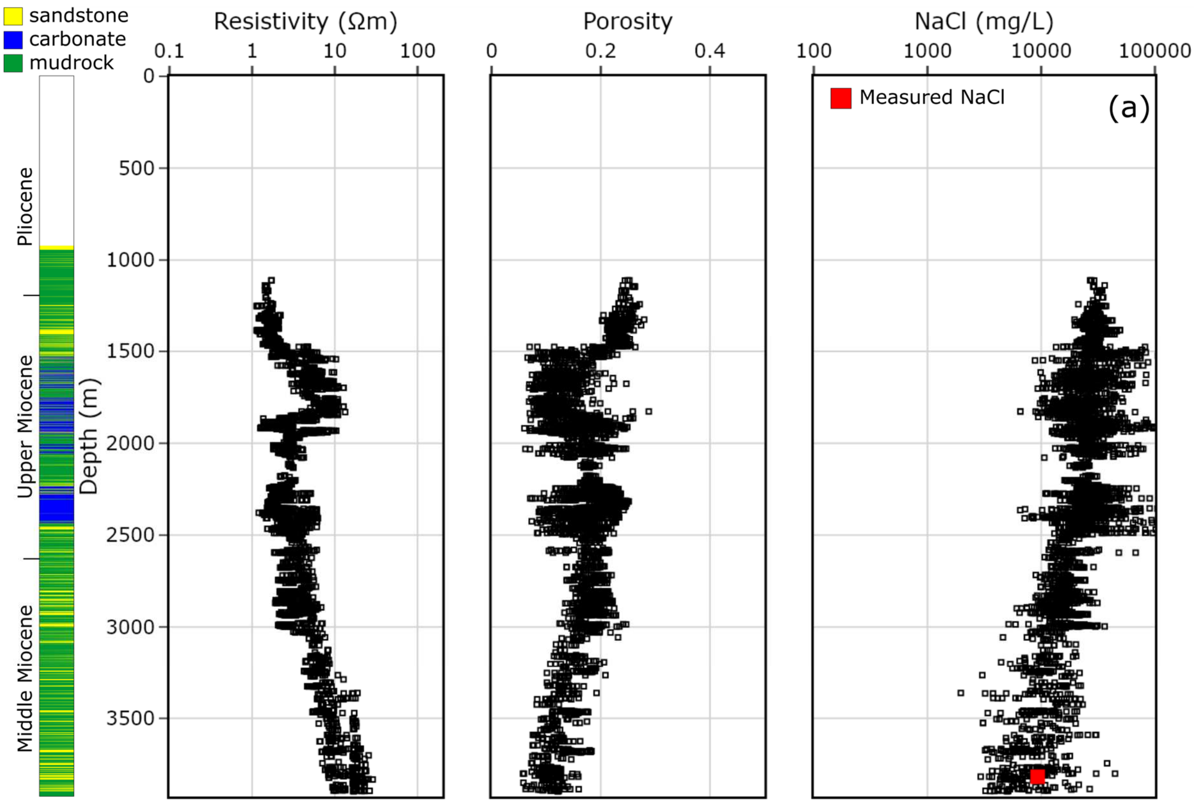


Fig. S36 The result of NaCl estimation at **a** Well no. 1 and **b** Well no. 2



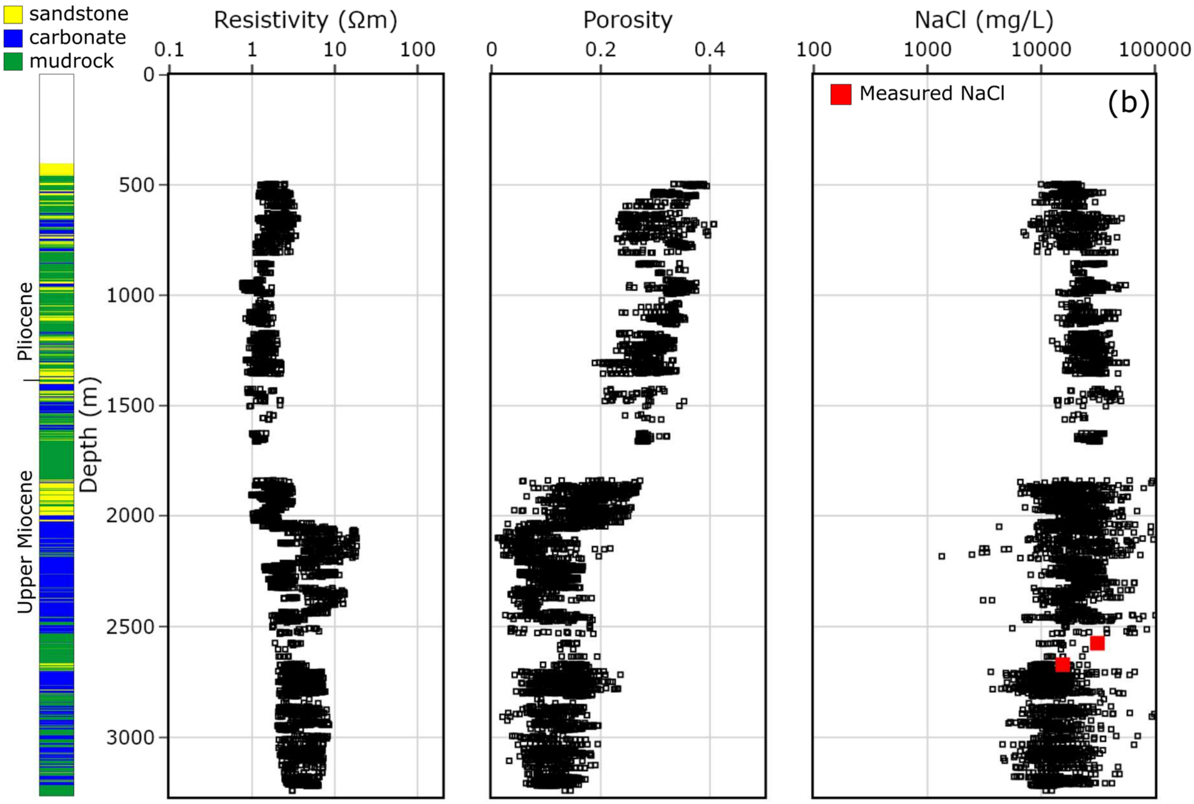


Fig. S37 The result of NaCl estimation at **a** Well no. 4 and **b** Well no. 5

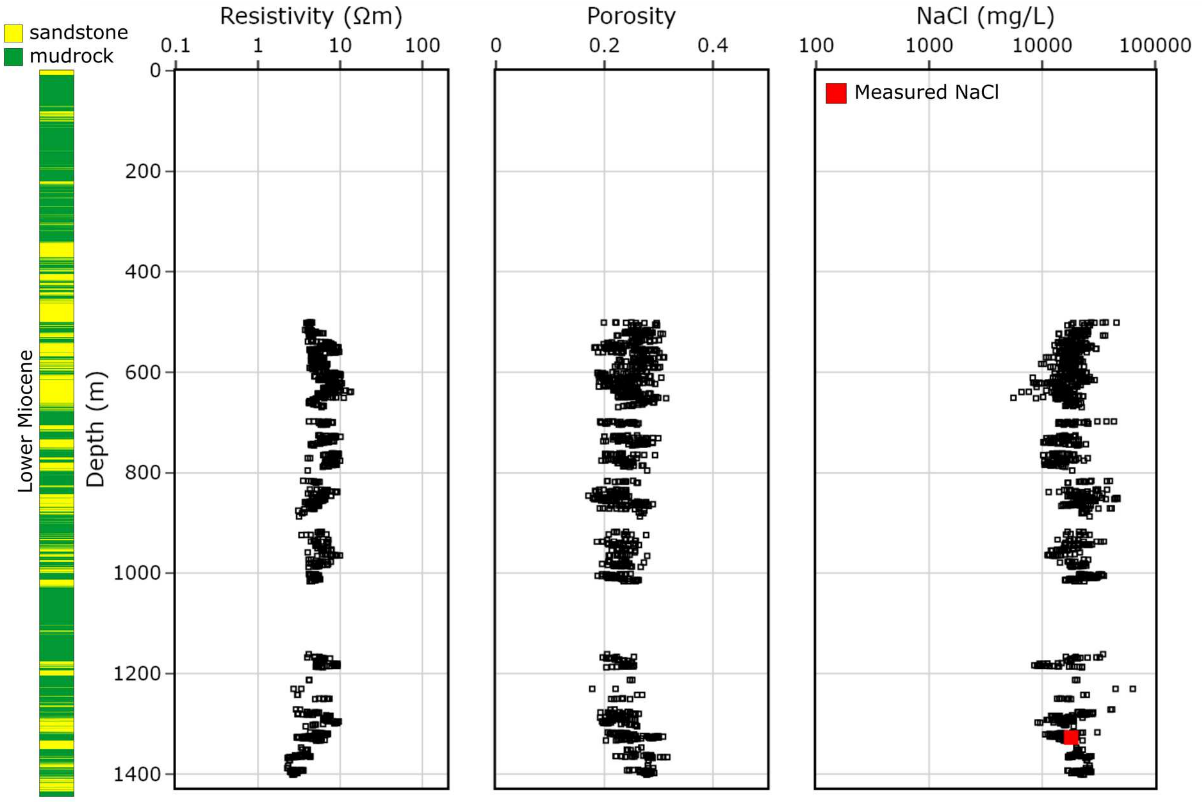


Fig. S38 The result of NaCl estimation at Well no. 7

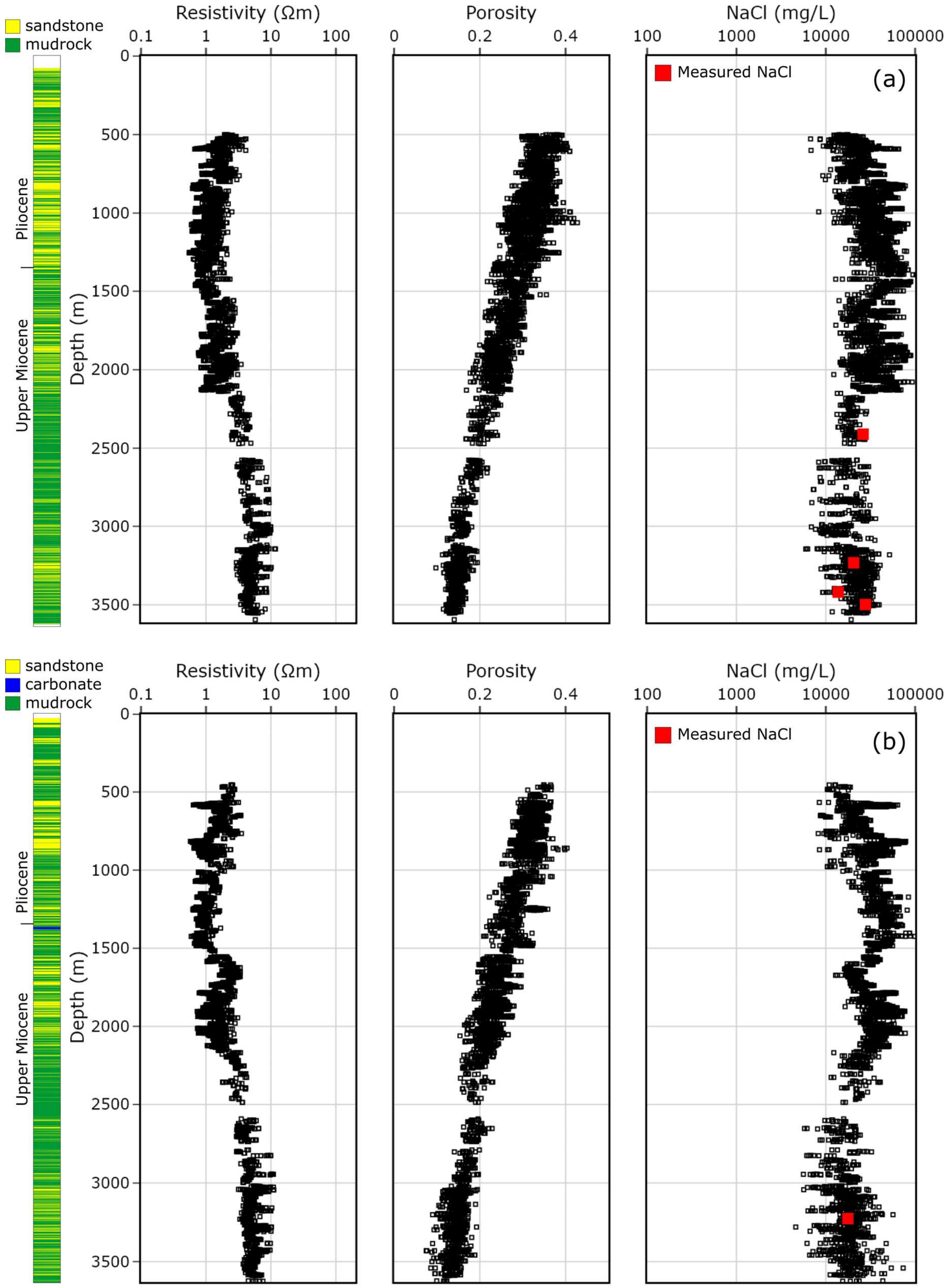
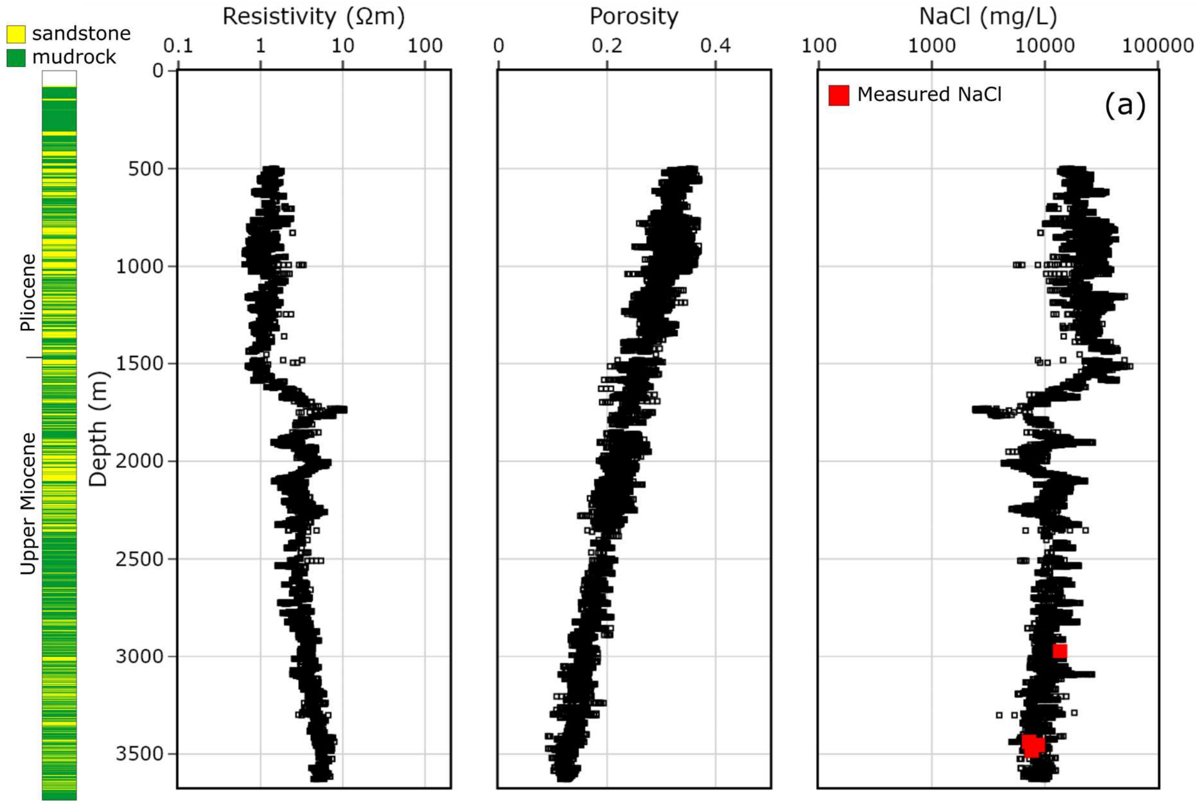


Fig. S39 The result of NaCl estimation at **a** Well no. 10 and **b** Well no. 11



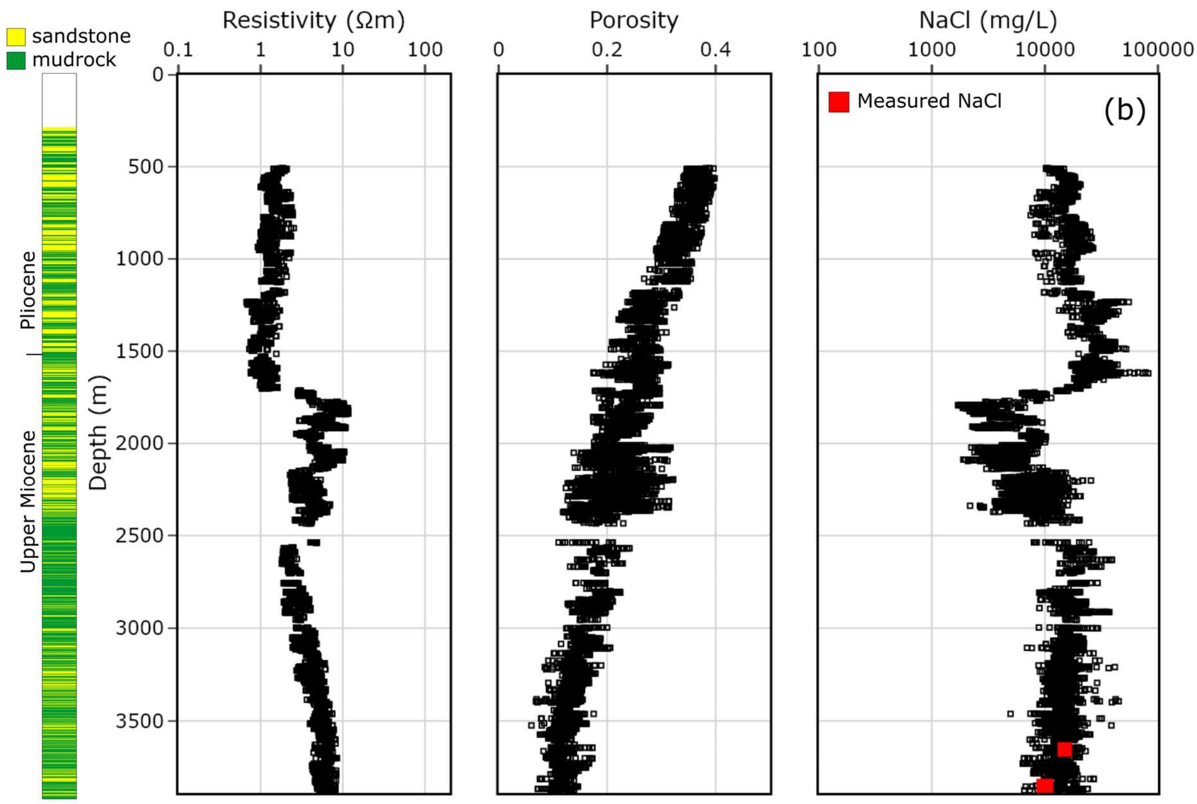


Fig. S40 The result of NaCl estimation at **a** Well no. 12 and **b** Well no. 13

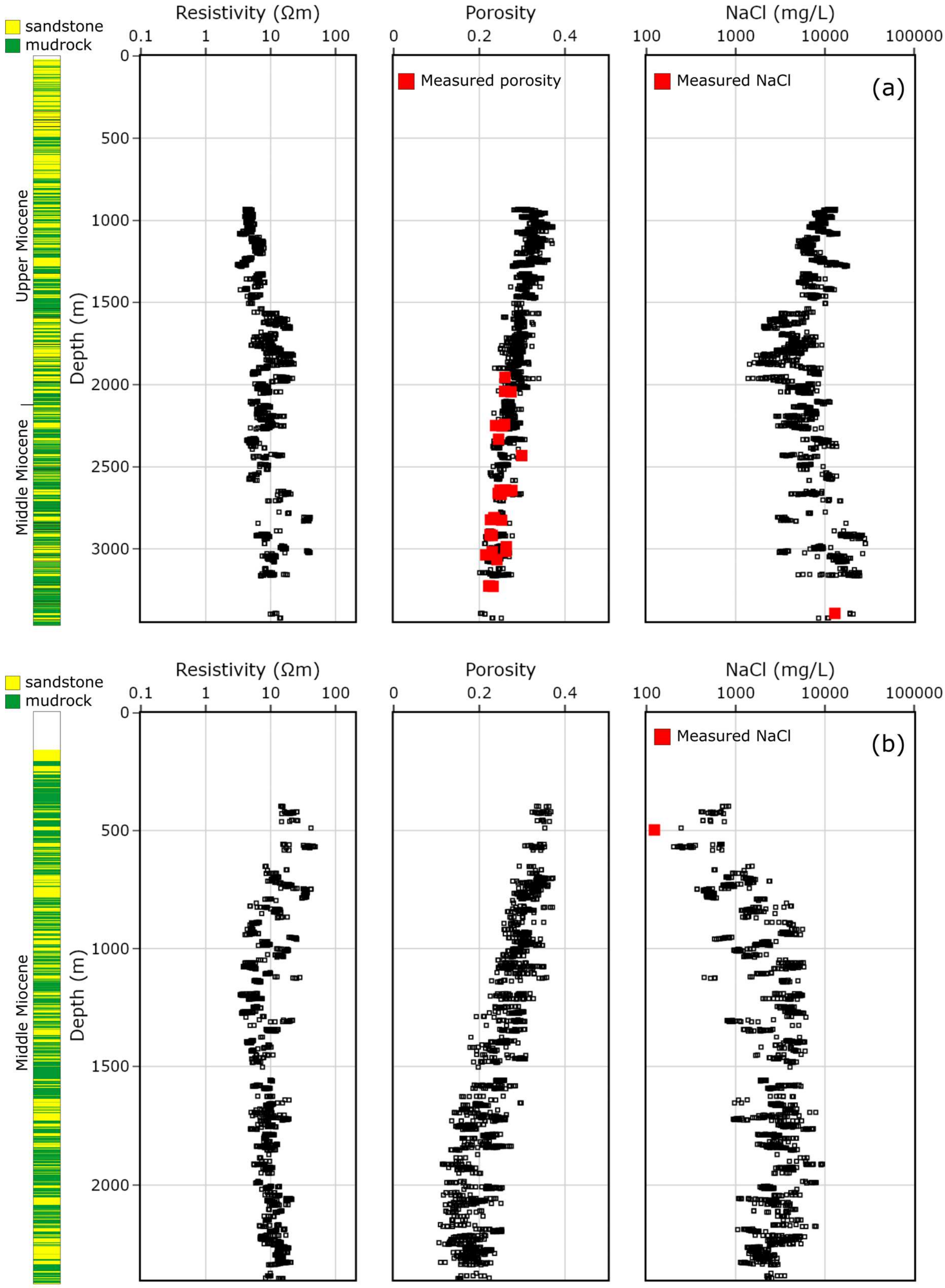


Fig. S41 The result of NaCl estimation at **a** Well no. 16 and **b** Well no. 17

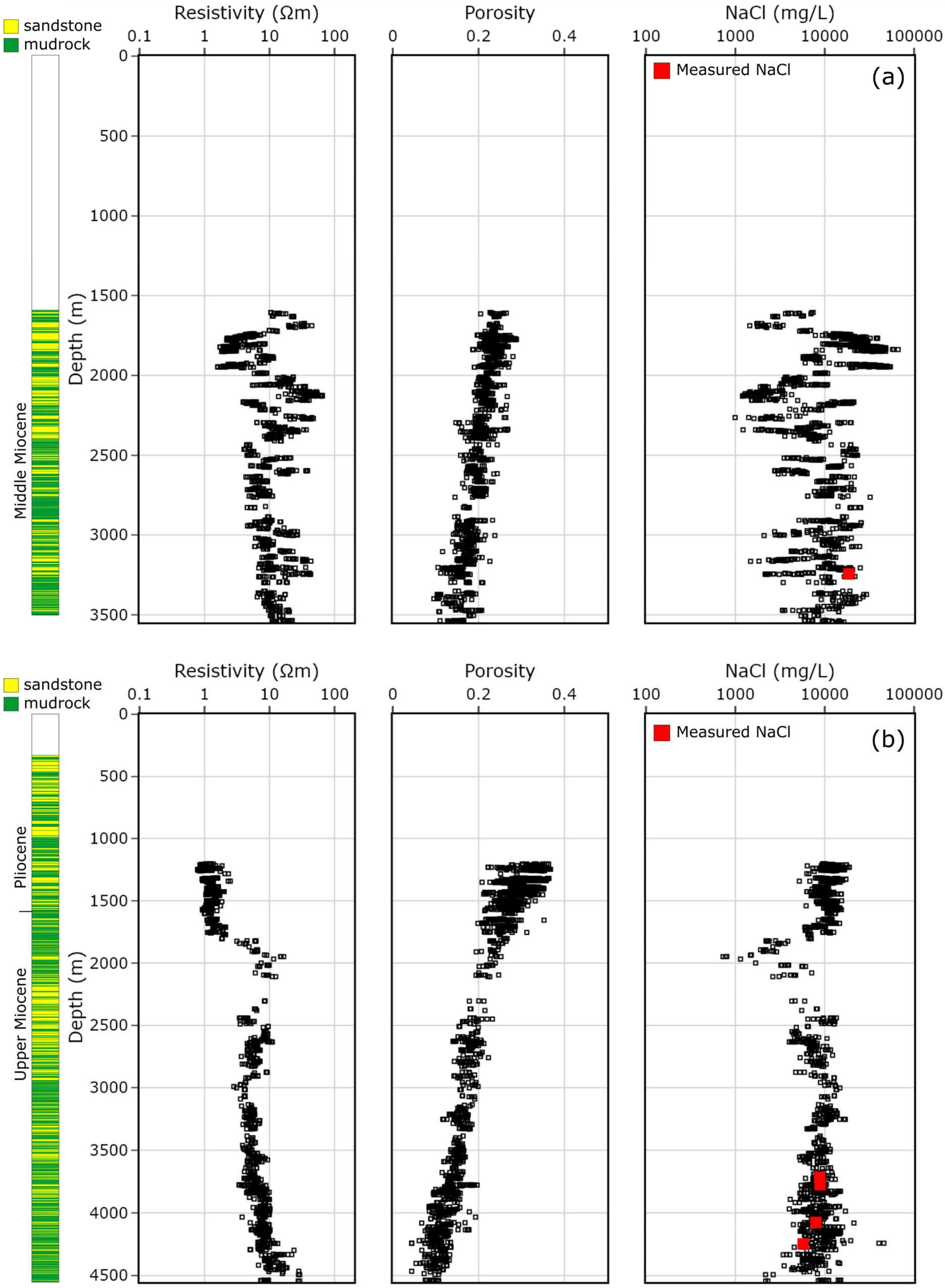


Fig. S42 The result of NaCl estimation at **a** Well no. 19 and **b** Well no. 20

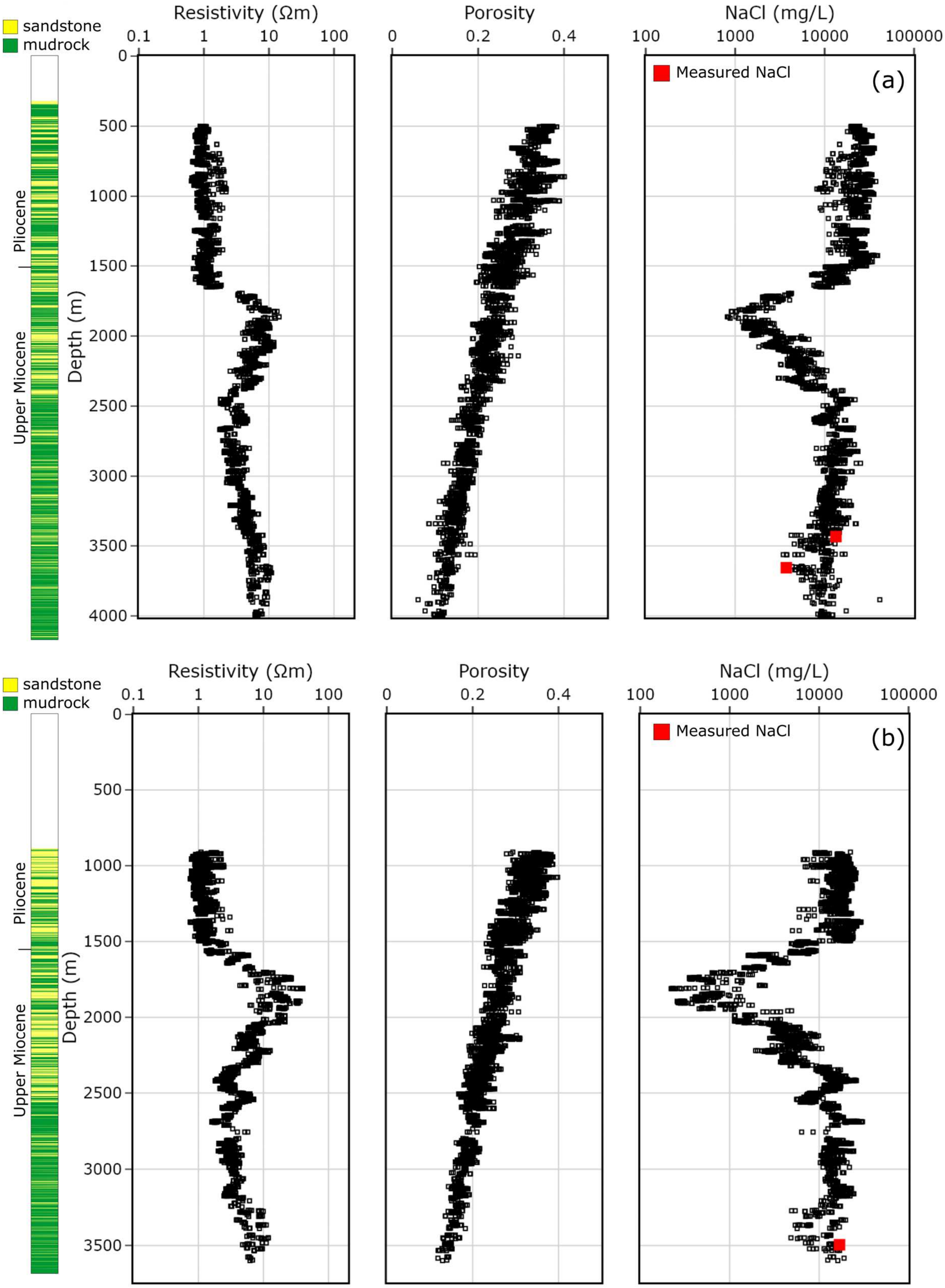
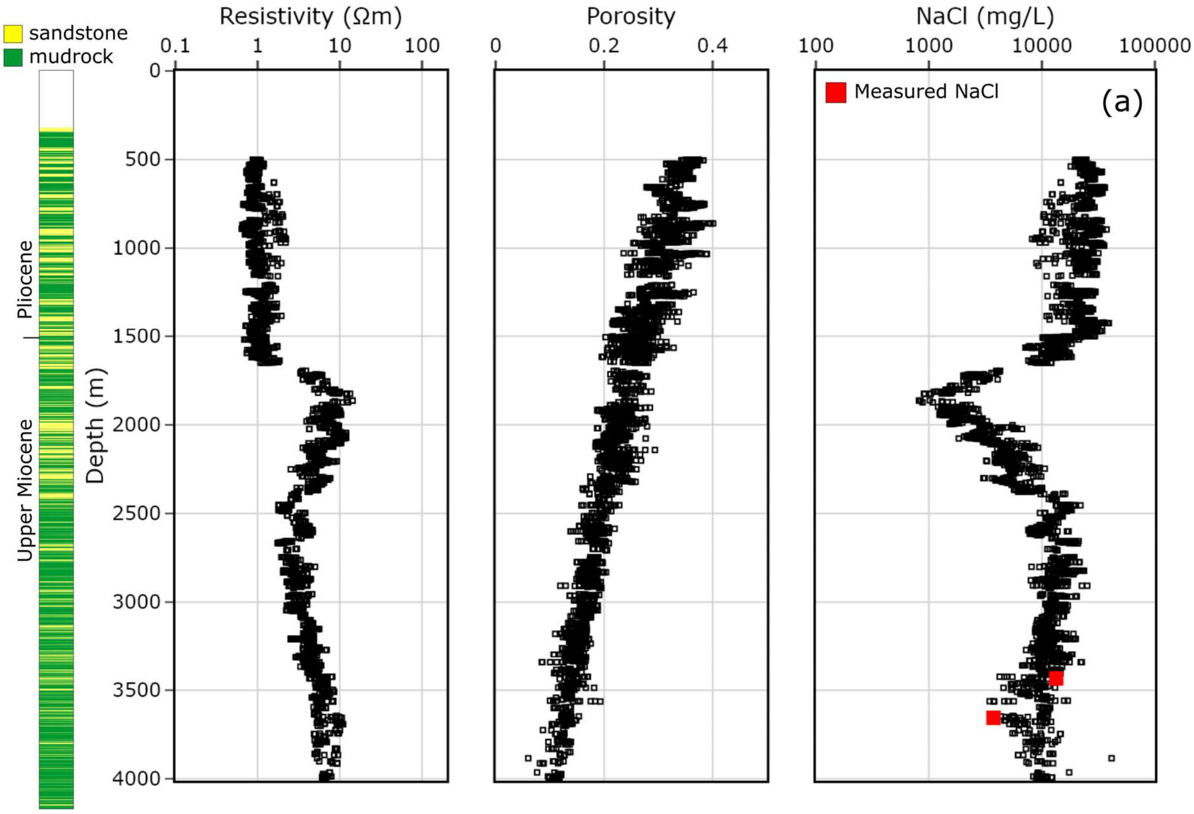


Fig. S43 The result of NaCl estimation at **a** Well no. 22 and **b** Well no. 24



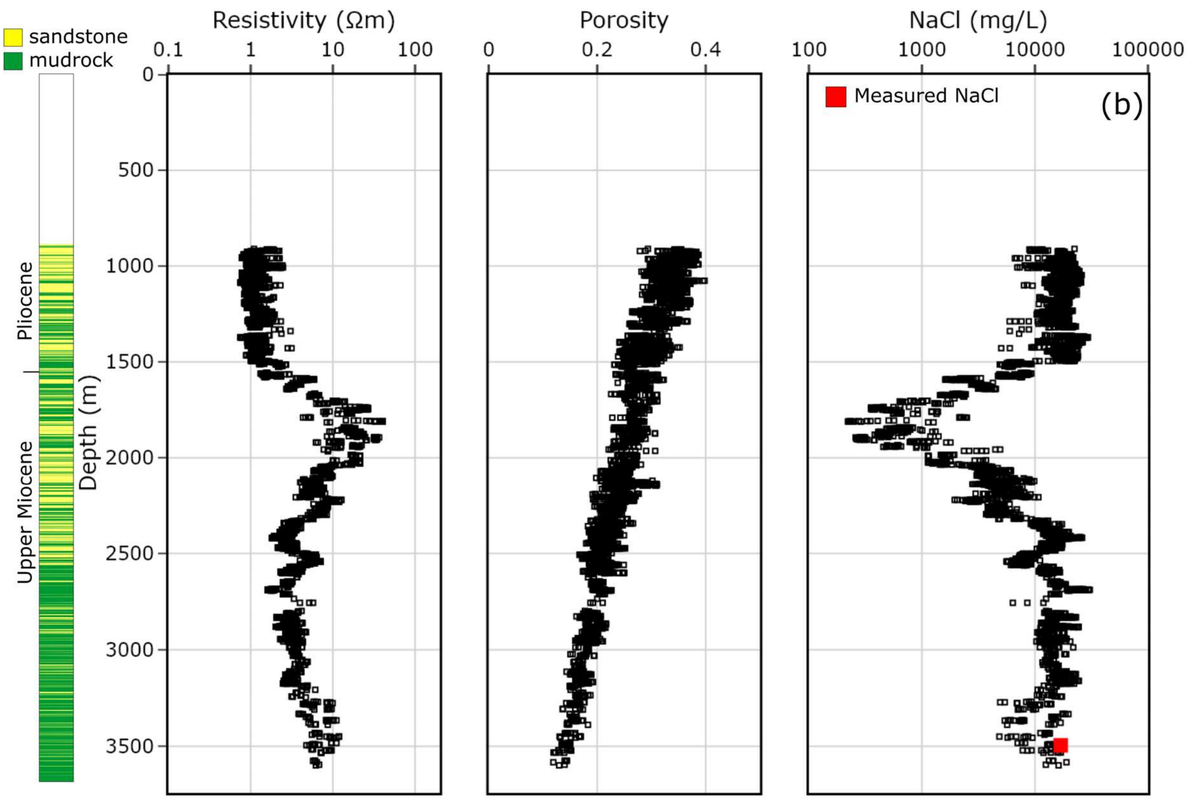


Fig. S44 The result of NaCl estimation at **a** Well no. 25 and **b** Well no. 26

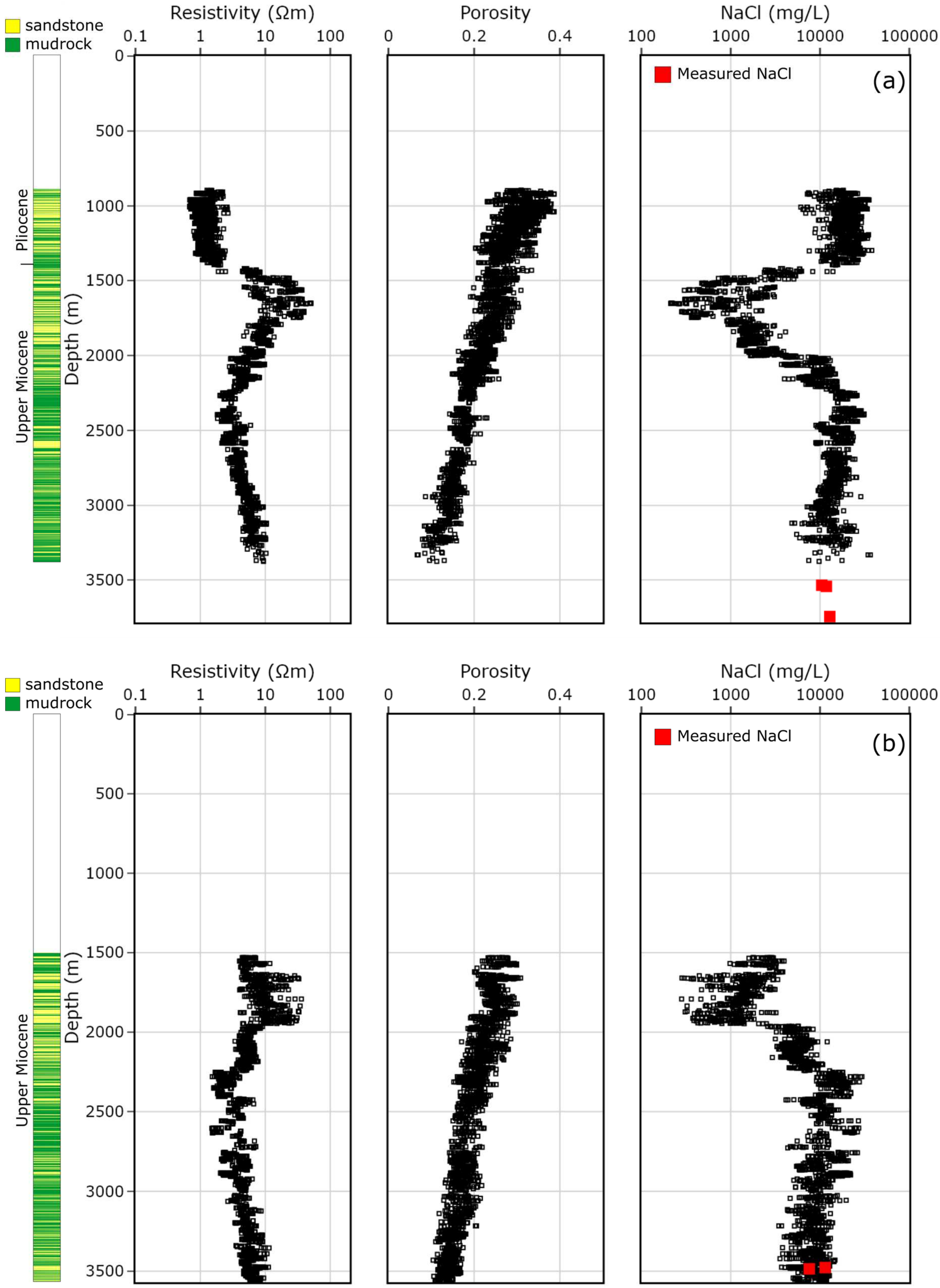


Fig. S45 The result of NaCl estimation at **a** Well no. 27 and **b** Well no. 28

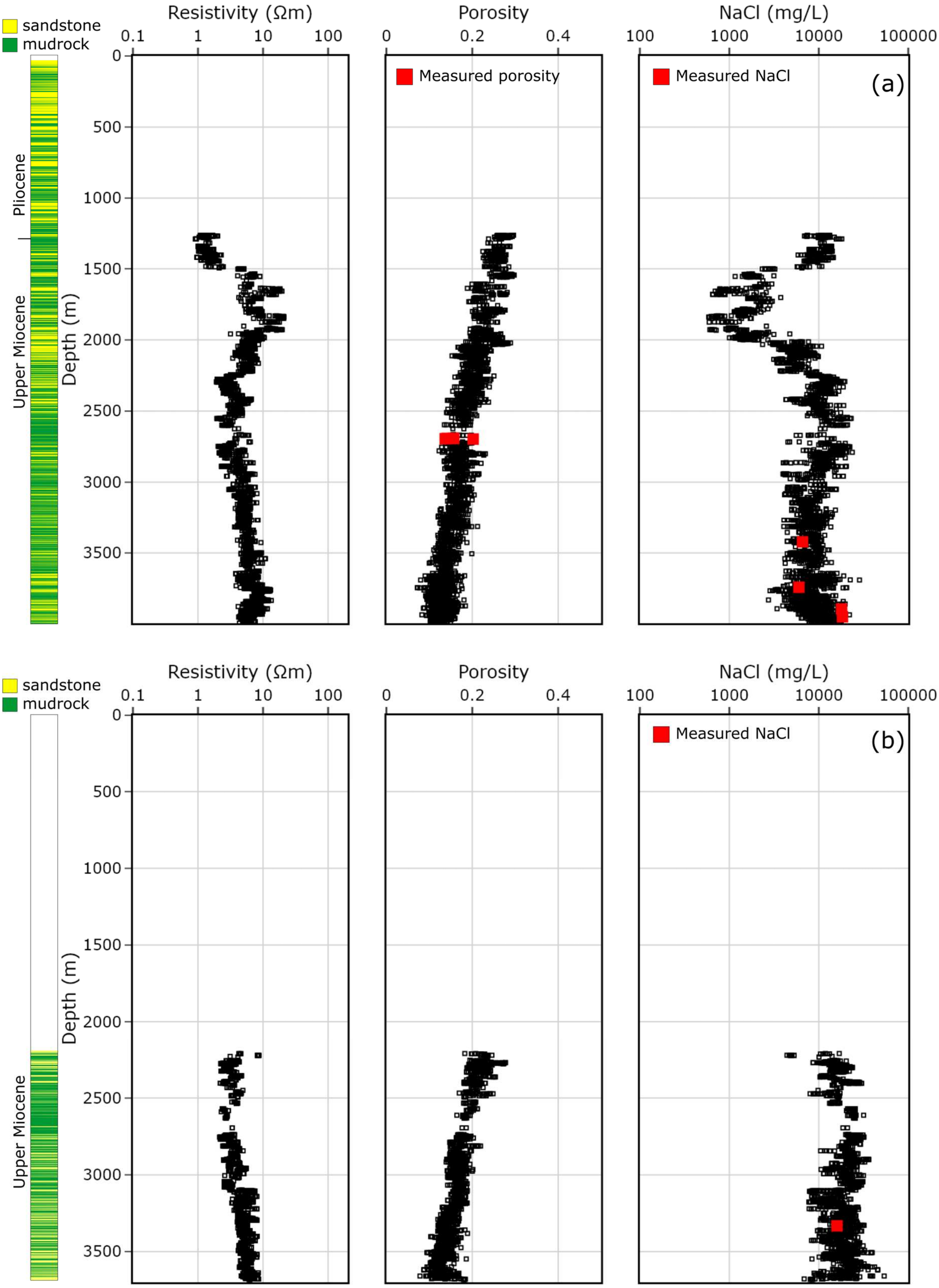


Fig. S46 The result of NaCl estimation at **a** Well no. 29 and **b** Well no. 30

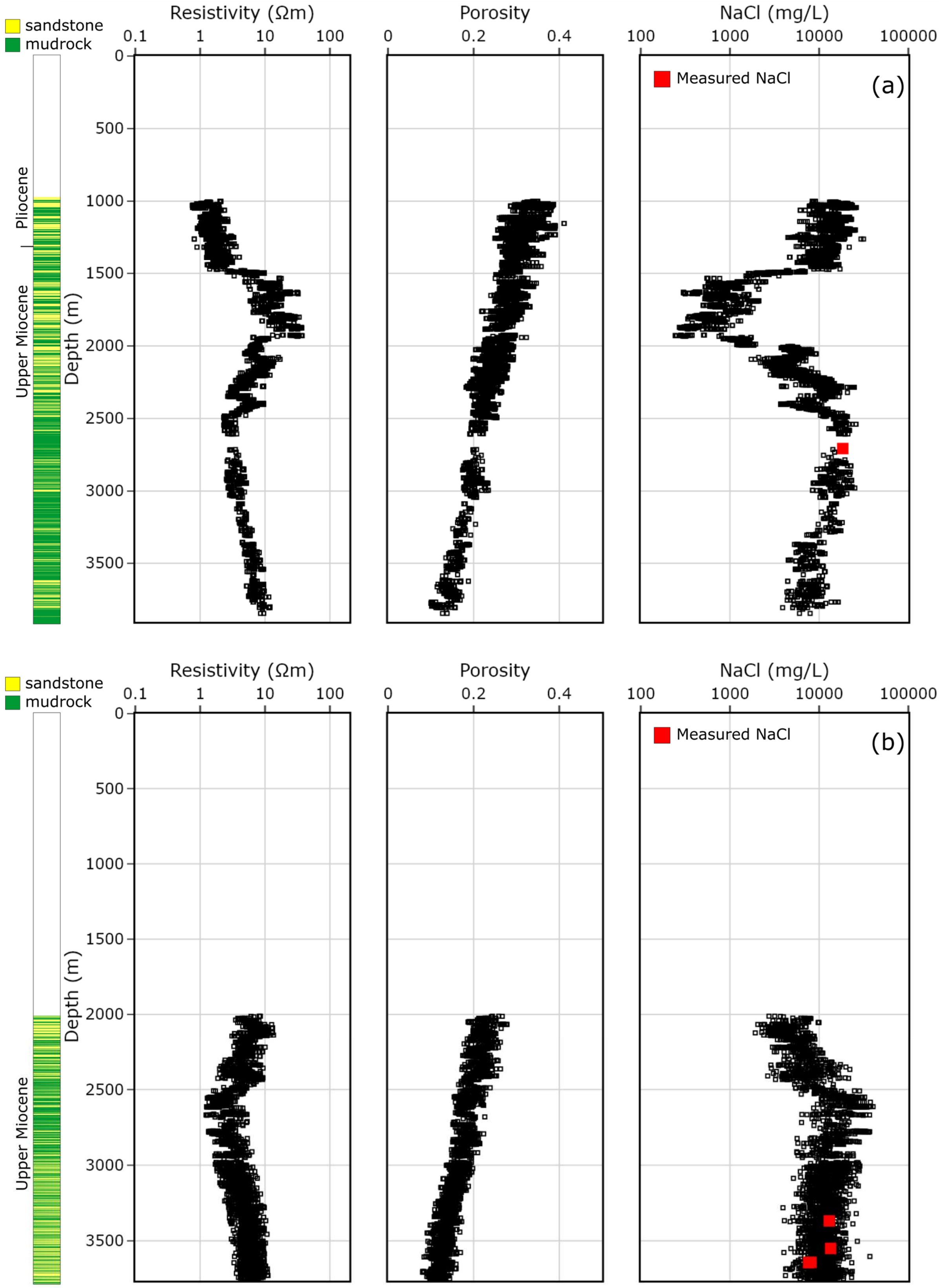
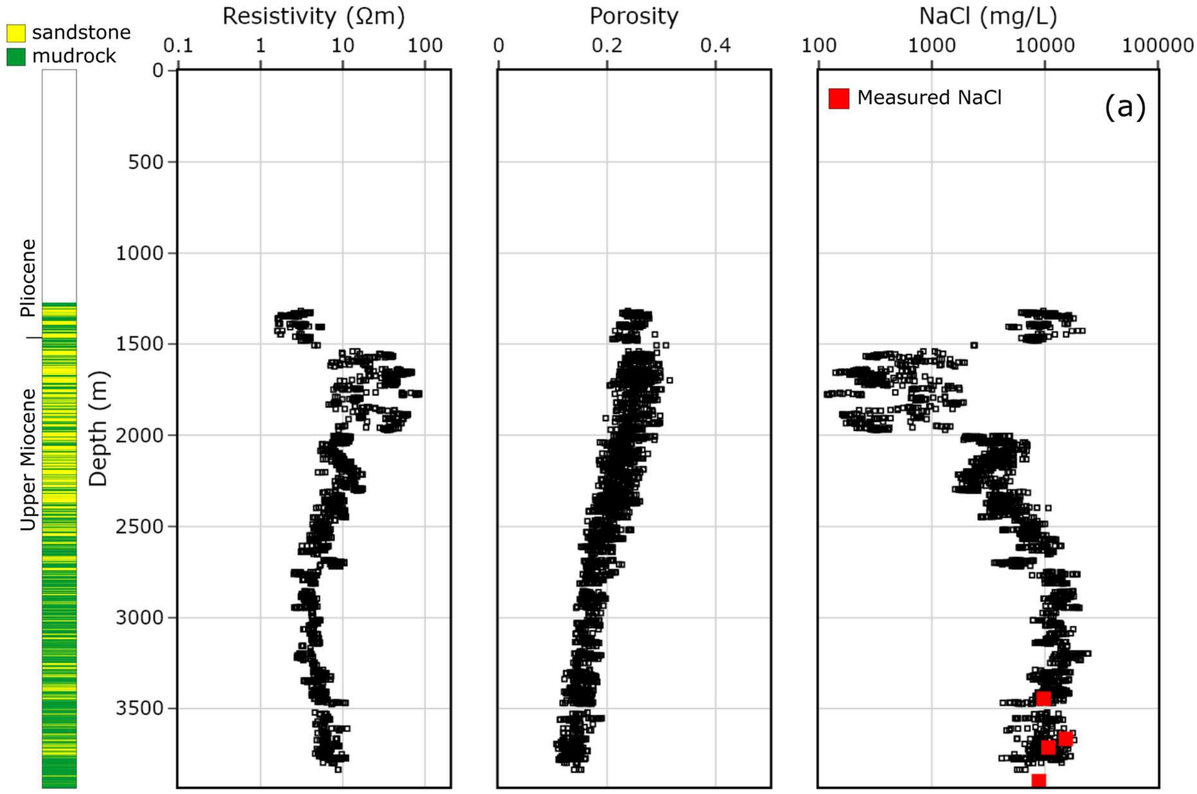


Fig. S47 The result of NaCl estimation at **a** Well no. 32 and **b** Well no. 33



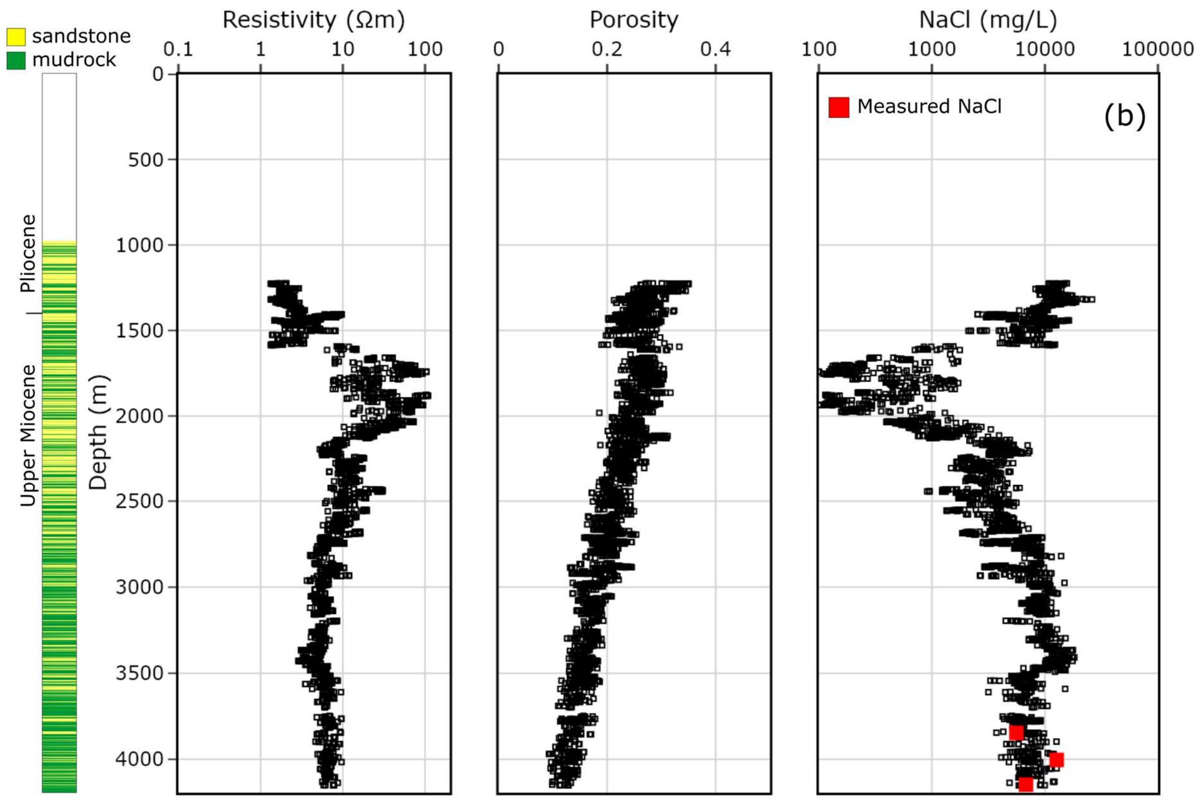
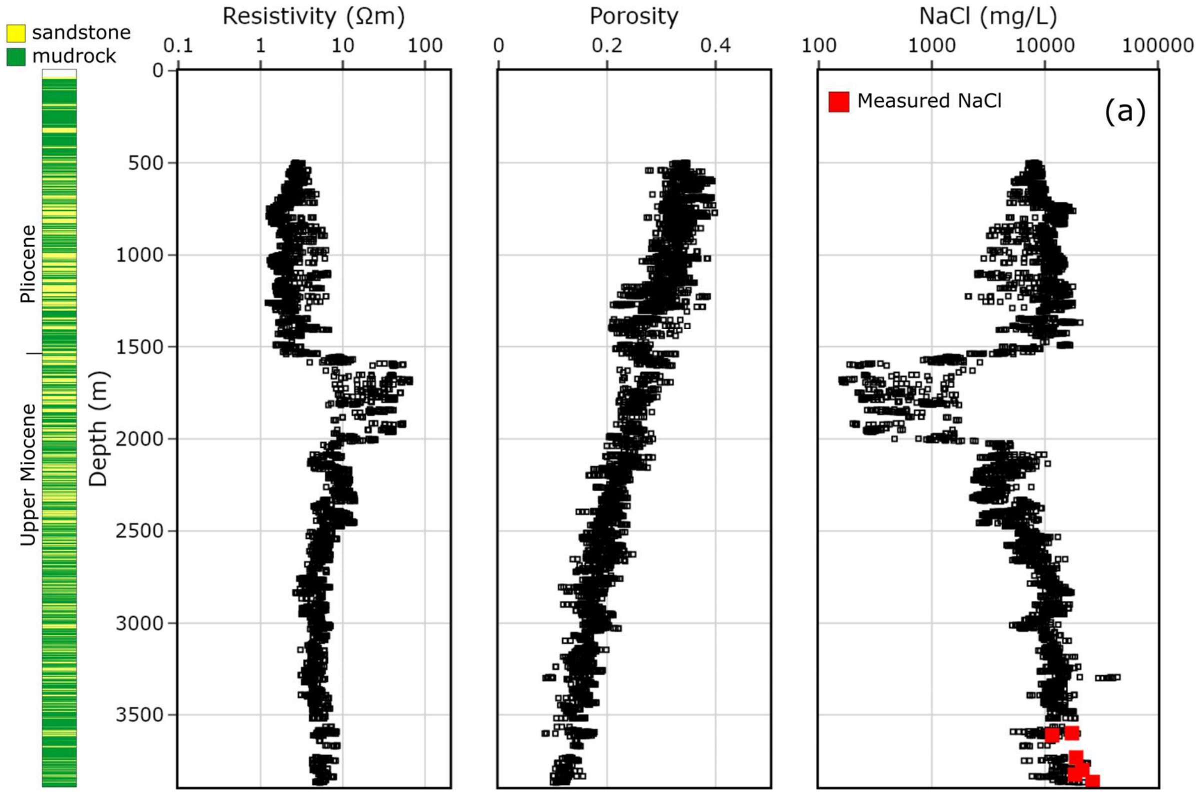


Fig. S48 The result of NaCl estimation at **a** Well no. 34 and **b** Well no. 35



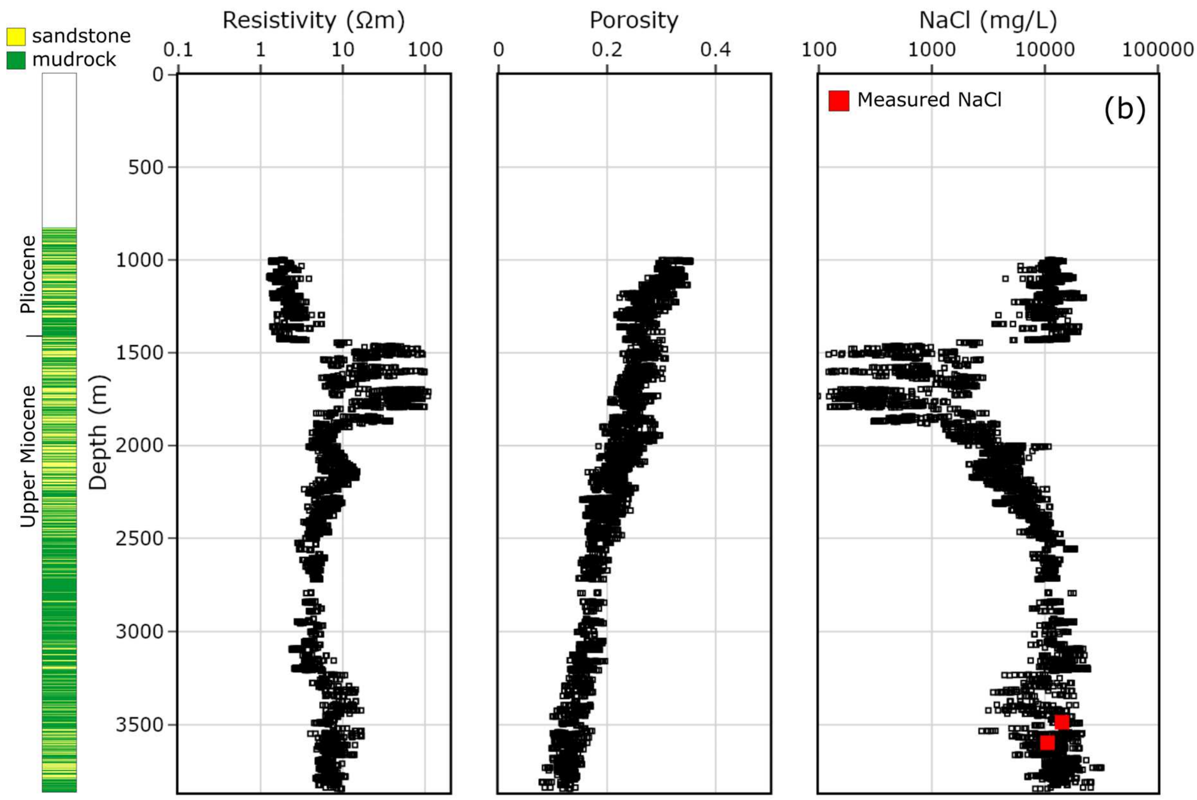


Fig. S49 The result of NaCl estimation at **a** Well no. 36 and **b** Well no. 37

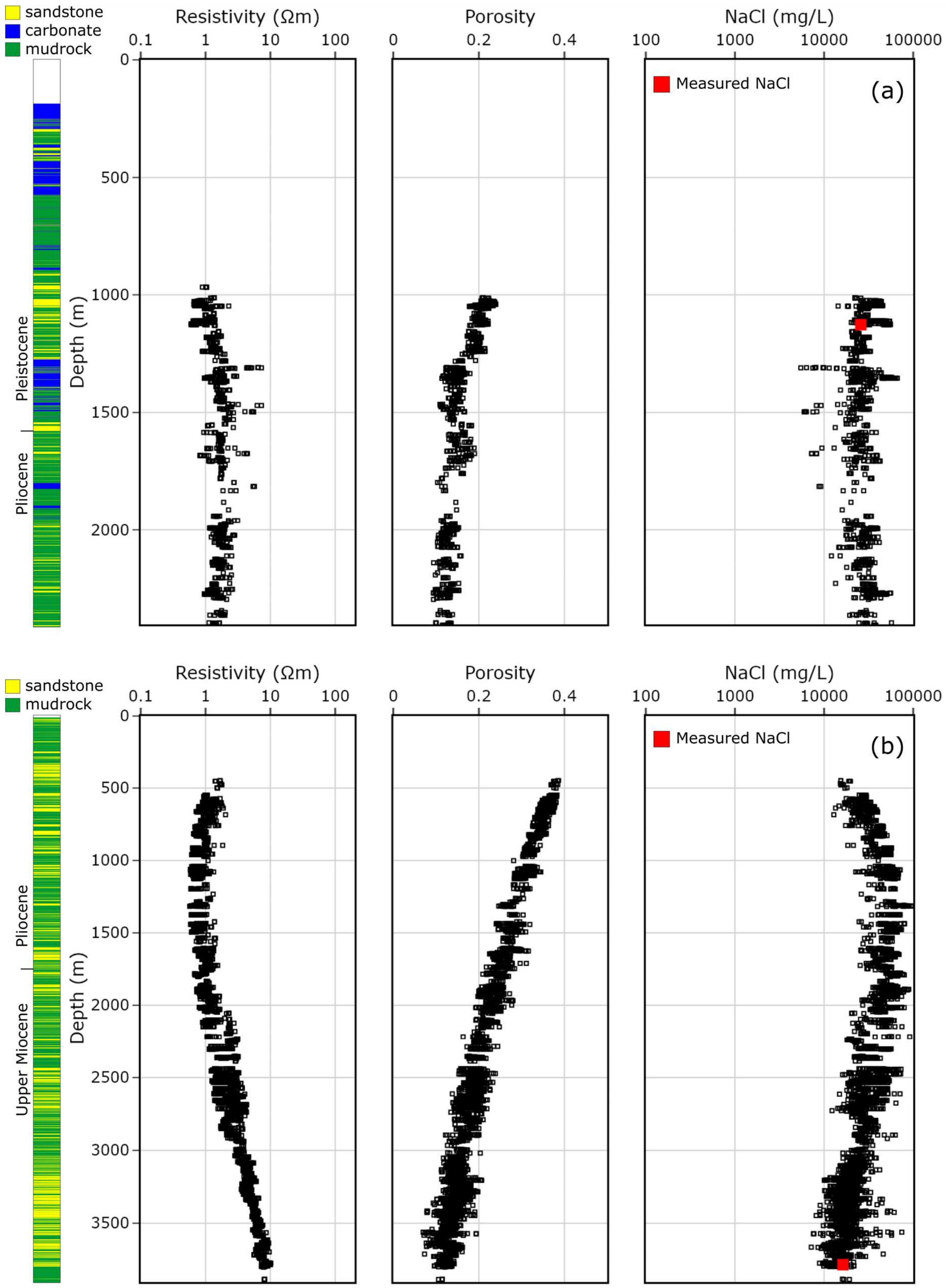


Fig. S50 The result of NaCl estimation at **a** Well no. 38 and **b** Well no. 39

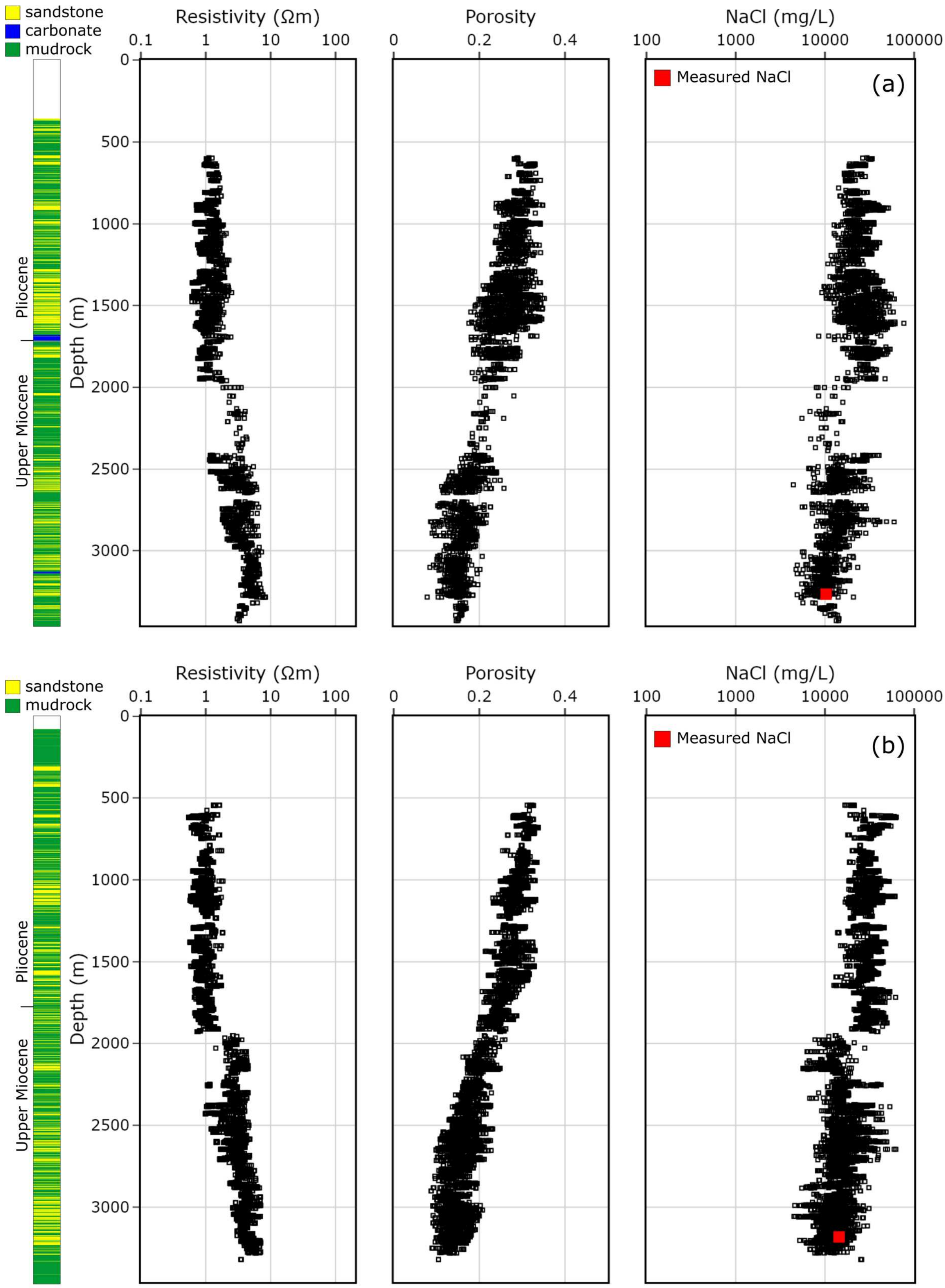


Fig. S51 The result of NaCl estimation at **a** Well no. 40 and **b** Well no. 41

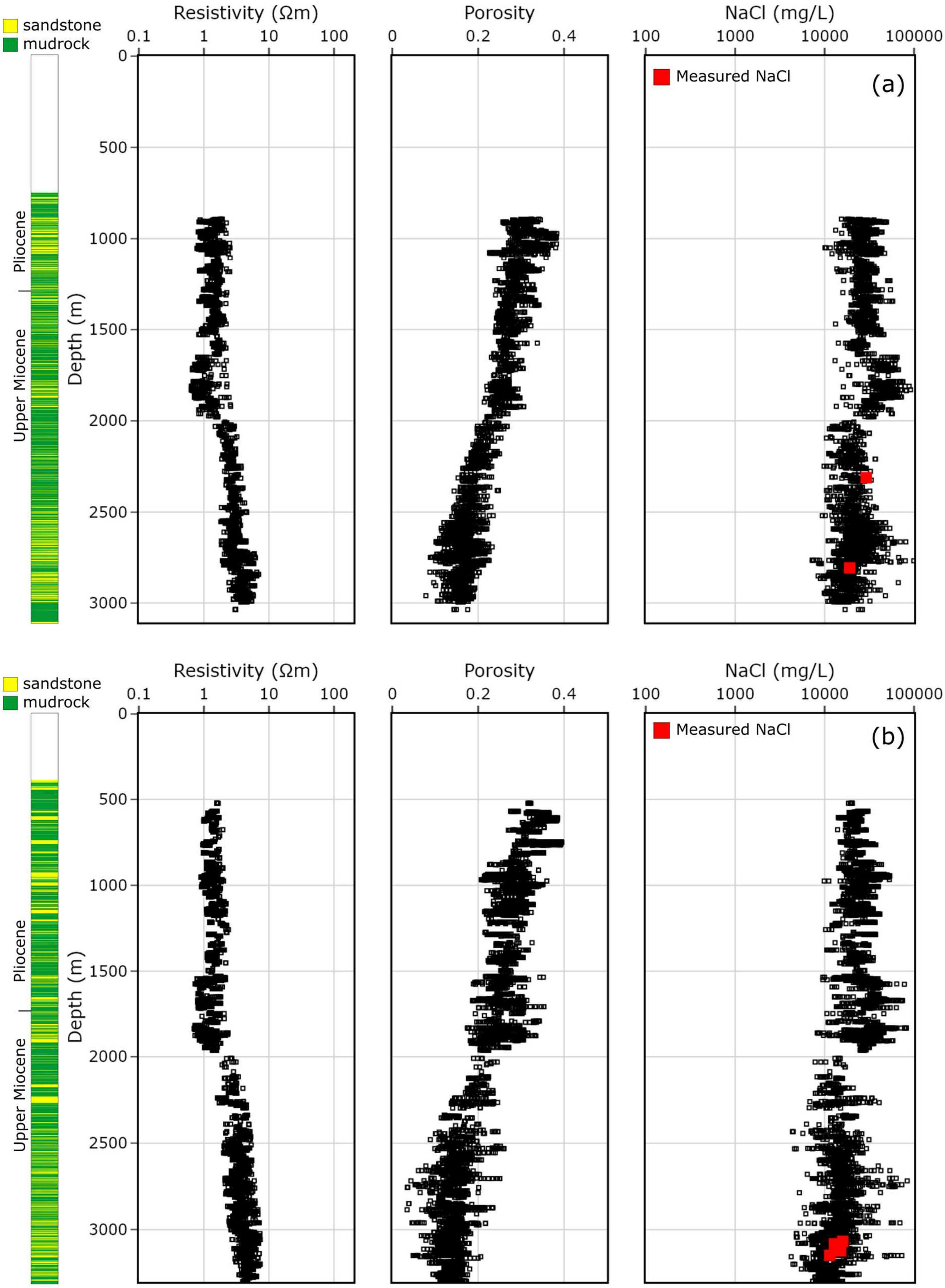


Fig. S52 The result of NaCl estimation at **a** Well no. 42 and **b** Well no. 43

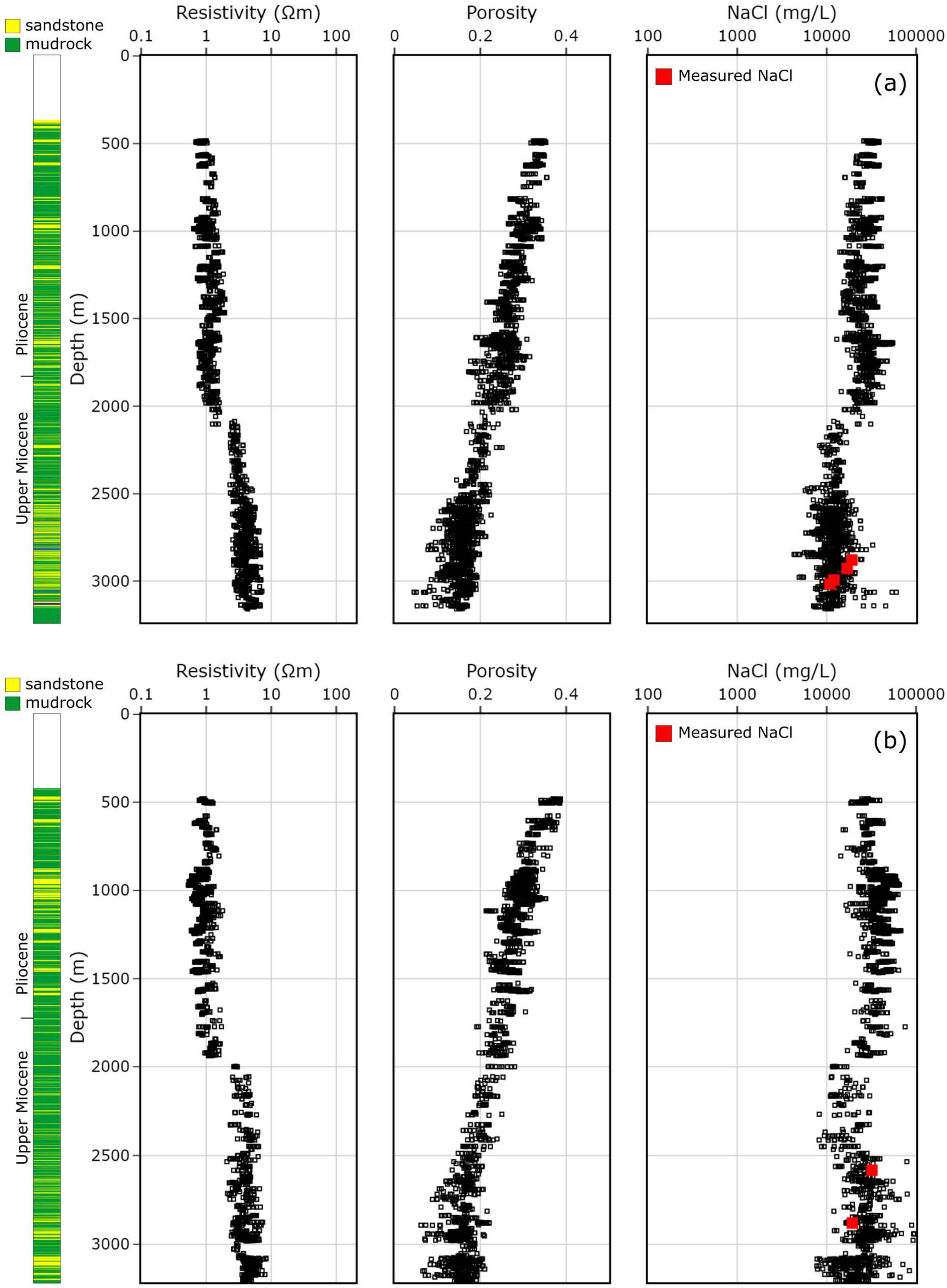


Fig. S53 The result of NaCl estimation at **a** Well no. 44 and **b** Well no. 45

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