SUPPLEMENTARY INFORMATION – Bakakas et al.

Methods

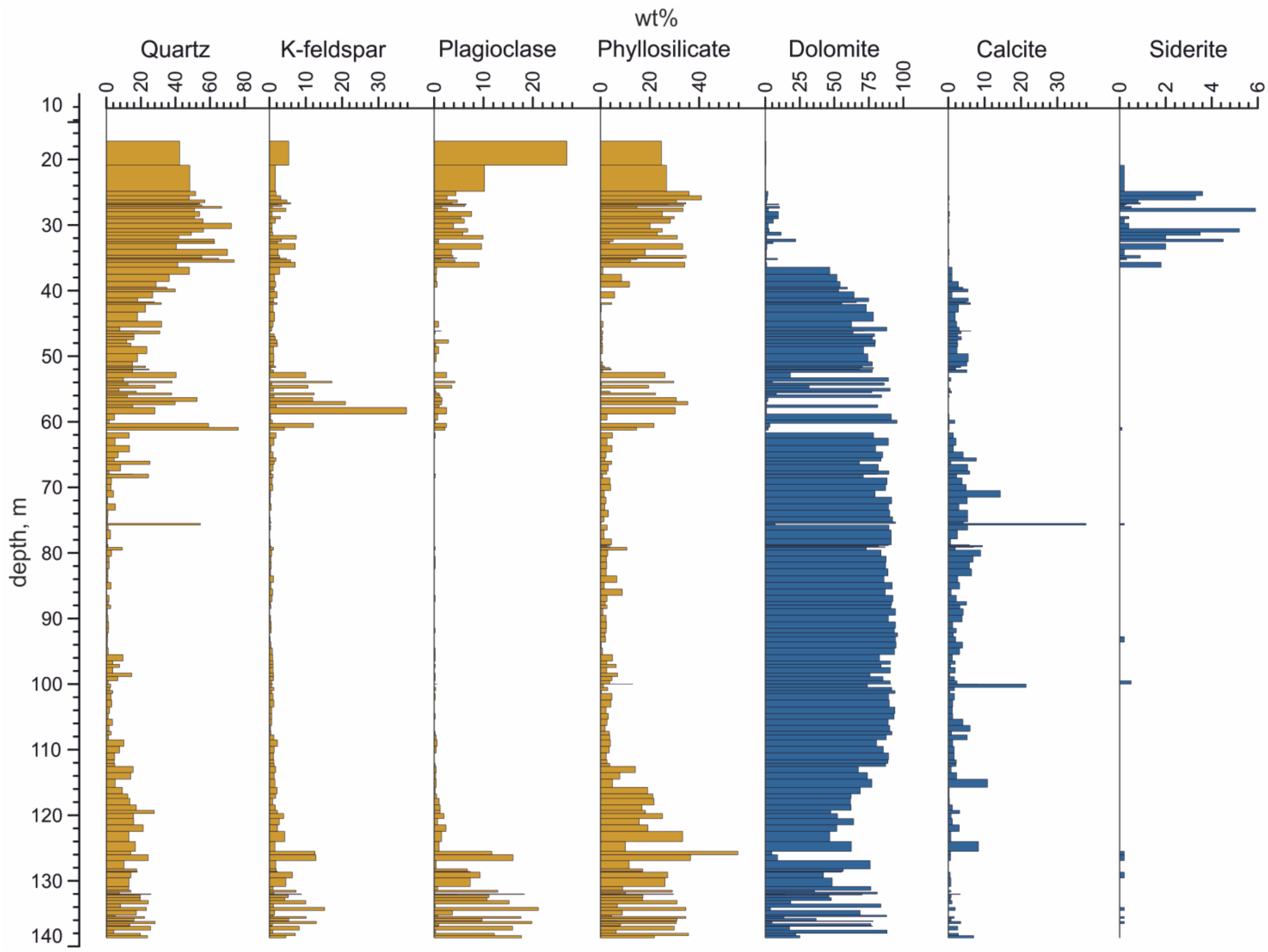
Mineralogical compositions of 150 samples were determined by X-ray diffraction (XRD) method from unoriented preparations on a Bruker D8 Advance diffractometer using Cu *K*α radiation and LynxEye positive sensitive detector in 2-70° 2Θ range (Tartu University). Composition was interpreted and modelled using the Rietveld algorithm-based programme Topaz. Relative error of quantification is better than 10% for major phases (>5 wt %) and better than 20% for minor phases (<5 wt %). Major and minor element composition of 60 pulverised samples dissolved with multi-acid methods (HNO_3, $HClO_4$, HF) was determined by ICP-OES (Bureau Veritas Minerals, Canada). Average relative standard deviation was less than 5% for all elements.

Stable C and O isotope ratios ($\delta^{13}C$ and $\delta^{18}O$) in calcite and dolomite, and C isotope ratios in organic matter, were measured on a Thermo Scientific Delta V Advantage continuous flow isotope ratio mass-spectrometer (Tartu University) following standard protocols and using the same powdered samples that were used for XRD. Carbonate stable isotope data are reported in *per mil* deviation relative to the Vienna PeeDee Belemnite (VPDB) standard and reproducibility was better than ±0.2‰ for both $\delta^{13}C$ and $\delta^{18}O$ (corrected for phosphoric acid fractionation factor for calcite and dolomite; Rosenbaum and Sheppard, 1986). Stable C isotope composition of organic carbon was measured in decarbonated sample powder after treatment with 10% (v/v) HCl to dissolve carbonate phases. In addition to bulk samples, C_{org} isotope compositions were also analysed from pyrobitumen veins and the adjacent host rock.

Thin sections and polished slabs were used for petrographic analyses by optical microscopy and SEM. SEM imaging of carbon-coated samples was done using a Zeiss EVO MA15 scanning electron microscope (Tartu University). Images were captured by backscattered electron mode and chemical characterisation by elemental mapping using an Oxford AZTEC-MAX energy-dispersive spectroscopy detector attached to the SEM.

Mineral composition

Studied LST12 core section is represented by unmetamorphosed dolomite-shale succession. Dolomite is the dominant primary carbonate phase and constitutes >90% of the mineral composition in the middle part of the section (See Supplementary Figure 1). In interbedded dolomitic silt-sandstones in the lowermost part of the core, the dolomite content varies from 20%to 85%. Dolomite content decreases from 60-80% in upper third of the section to <20% in uppermost part of the section represented by organic-rich shales where minor amount (up to 5%) of siderite occurs. Calcite content is typically <10% and occurs as secondary vein filling in brecciated and fractured intervals. The terrigenous fraction is composed of quartz - K-feldspar – plagioclase - phyllosilicate assemblage, which abundance is greatest in the lowermost and uppermost parts of the core. Phyllosilicates are represented by K-mica and chlorite and minor kaolinite.



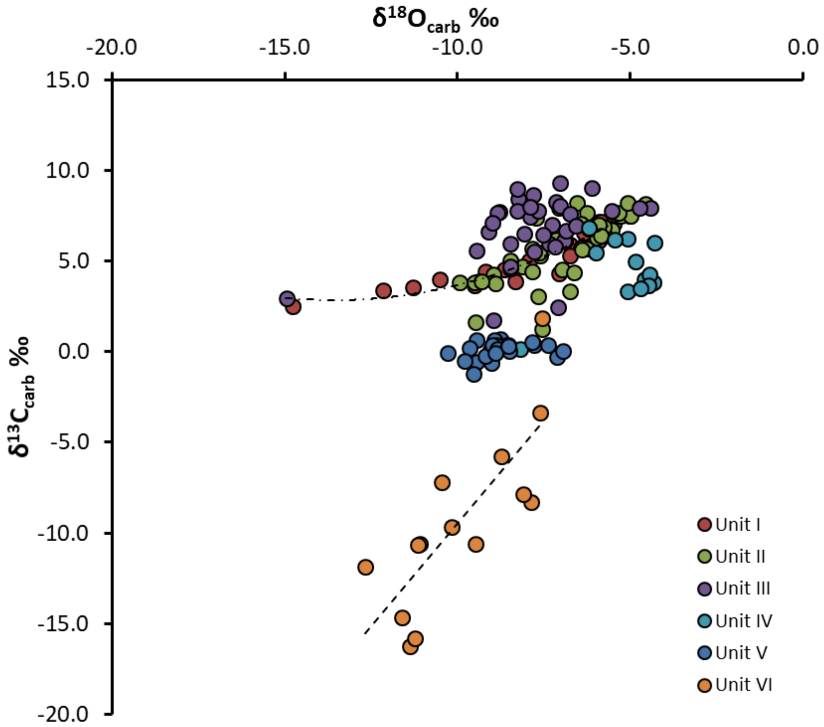
Supplementary Figure 1. Mineral composition of the LST12 section.

Preservation of the isotope signal

Carbonate rocks are considered to retain syndepositional $\delta^{13}C_{carb}$ values under diagenetic recrystallization and low-grade metamorphism (Hood et al., 2018; Schidlowski, 2001; Swart, 2015). In contrast, the oxygen isotopic composition can be readily reset even under diagenetic conditions (Banner and Hanson, 1990). Both $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values can be altered by meteoric diagenesis and diagenetic/hydrothermal dolomitization depending on composition of the rock and fluid, the fluid/rock ratio and open-system or closed-system during the alteration (Banner and Hanson, 1990).

The preservation of the geochemical signal of the LST12 section was assessed, along with petrographic and mineralogical criteria, by cross-plotting carbonate $\delta^{13}C$ and $\delta^{18}O$ values (Supplementary Figure 2). A positive correlation and diagenetic alteration trend towards negative $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values is evident in organic-rich carbonates in Unit VI, which is further confirmed by petrographic analysis showing multi-zoned Mn/Fe-rich dolomite and siderite crystal aggregates of late diagenetic origin (see Figure 4 in Main Text). The negative $\delta^{13}C_{carb}$ values between -5 and -17‰ suggest carbon derived from mixing of seawater DIC pool with ^{13}C depleted carbon from remineralization of organic matter.

There is no correlation between $\delta^{13}C$ and $\delta^{18}O$ values in Units II through IV indicating preservation of the primary $\delta^{13}C$ signal. We cannot rule out resetting of carbonate $\delta^{18}O$ values in the course of diagenetic recrystallization as suggested from petrographic observations (notice Fe-rich rims in dolomite crystallites in Figure 4 in Main Text) but lack of significant covariation between $\delta^{13}C$ and $\delta^{18}O$ values suggests that the C-isotope system has remained closed in these units.



Supplmentary Figure 2. Cross-plot of the carbonate $\delta^{18}O$ and $\delta^{13}C$ values measured in LST12. Note a positive covariation in $\delta^{18}O_{carb}$ and $\delta^{13}C_{carb}$ values in Unit VI represented mainly by diagenetic carbonates. The curved positive covariation between $\delta^{18}O_{carb}$ and $\delta^{13}C_{carb}$ values in mixed shale-carbonate of Unit I results from diagenetic alteration where O-isotope values are reset more readily compared with C-isotope values. The $\delta^{13}C_{carb}$ values of least altered samples in Unit I from thick carbonate beds are consistent with Units II-IV and vary between 6-7‰.

In Unit I, consisting of shallow-water siltstone/shale-carbonate interbeds, the $\delta^{18}O$ and $\delta^{13}C$ values for samples from impure carbonate beds with higher proportions of terrigenous phases (quartz, feldspars, phyllosilicates) plot on a curved line with a gentle positive slope indicating preferential resetting of $\delta^{18}O$ values with respect to $\delta^{13}C$ values. Such non-linear covariance between $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values is characteristic to partial resetting of the O isotopic system due to fluid-rock interaction (Banner and Hanson, 1990; Bishop et al., 2014; Jacobsen and Kaufman, 1999). As the $\delta^{18}O$ values are more readily reset during partial alteration, a $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ trend paralleling the oxygen axis forms. If, however, the alteration proceeds, then $\delta^{13}C_{carb}$ values can also become progressively reset producing a characteristic L-shape curve of $\delta^{18}O_{carb}$ and $\delta^{13}C_{carb}$ values in $\delta^{18}O_{carb}$ vs $\delta^{13}C_{carb}$ space. Given the resetting of $\delta^{18}O_{carb}$ values and only slight modification of the $\delta^{13}C_{carb}$ values in Unit I, we suggest that these rocks have experienced a partial diagenetic overprint that affected mainly the O-isotope composition. The most negative $\delta^{18}O_{carb}$ and partly reset $\delta^{13}C_{carb}$

values around 3-4‰ are found in inter-beds with the highest terrigenous material content. The carbonate beds with total carbonate content >60% have, however, retained their $\delta^{13}C_{carb}$ values of c. 7‰. This suggests that interbeds with more terrigenous material and likely higher porosity have acted as fluid conduits where open-system partial resetting of particularly O-isotopes and to lesser extent of C-isotopes occurred. The $\delta^{13}C_{carb}$ values of the least altered carbonate-rich beds in Unit I are in the range of 5 to 7‰ in accordance with values in Units II-IV of the section. It is thus unlikely that diagenetic resetting and stronger overprint on dolorhythmite and -laminate of Unit V compared to the more massive dolostones of underlying Units could explain the observed $\delta^{13}C_{carb}$ trend from 6-7‰ to 0‰. There is no obvious petrographic nor isotopic and geochemical evidence for such resetting, but even if carbonates of Unit V ($\delta^{13}C_{carb}$ = c 0‰) were effectively reset under open system conditions, they must have been exposed to a large oceanic DIC pool which $\delta^{13}C$ value at the time were c 0‰ supporting, thus, our interpretation. In summary, excepting Unit VI and certain interbed intervals in Unit I, the $\delta^{13}C_{carb}$ values in LST12 record the original isotopic composition of contemporaneous seawater DIC.

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Supplementary Table 1
Mineral composition, wt. tr - <0.5 wt%

No.	Sample	depth, m	Quartz	K-feldspar	Plagioclase	Chlorite	K-mica	Kaolinite	Calcite	Dolomite	Siderite	Pyrite	Apatite
1	LST12-1	17.2	42.4	5.3	26.9	9.1	9.3	6.3		0.5			
2	LST12-BS-1	24.6	48.3	1.6	1.0		23.0	3.7		tr.		12.7	
3	LST12-BS-2	25.1	51.7	1.8	4.4		32.8	3.1		1.9	3.6	0.7	
4	LST12-2	25.9	48.0	3.1	2.6		37.9	3.0		1.5	3.3	0.6	
5	LST12-BS-3	26.5	57.0	4.8	4.7		26.8	4.0		1.1	0.8	0.6	
6	LST12-BS-4	26.9	52.6	2.2	6.5		24.6	2.9		9.8	tr.	0.9	
7	LST12-4b	26.9	55.3	3.4	6.2	2.5	27.4	3.8		0.7		tr.	
8	LST12-BS-5	27.4	66.8	0.8	1.5		10.6	4.1		10.3	0.5	5.4	
9	LST12-3b	27.5	51.0	4.5	2.7		30.5	2.9		2.3	5.9		
10	LST12-3	26.7	54.0	5.8	3.6		31.4	3.2		0.6	0.9	0.6	
11	LST12-BS-6	28.4	54.0	0.7	7.6		22.8	2.2	tr.	9.5		1.9	
12	LST12-4	29.0	51.0	3.0	5.4		27.3	2.6		9.5	tr.	0.7	
13	LST12-BS-7	29.1	56.0	1.6	6.1		25.3	3.0		5.8		0.9	
14	LST12-BS-8	30.3	72.4	0.7	3.9		17.6	2.5		2.1	tr.	tr.	
15	LST12-BS-9	30.8	56.2	0.7	6.8		25.0			2.8	5.2	2.2	
16	LST12-BS-10	31.4	49.2	0.9	5.8		23.0			11.4	3.5	4.2	
17	LST12-BS-11	31.8	41.9	7.4	9.9	2.2	28.9			1.0	2.0	4.8	
18	LST12-12bH	32.5	62.5	3.3	0.9		5.1			22.0	4.5		1.7
19	LST12-12bT	32.5	62.6	2.2	0.9		3.6			5.6			25.0
20	LST12-BS-13	33.2	40.5	7.1	9.6	1.5	28.4	3.4		1.2	2.0	4.6	
21	LST12-BS-14	34.2	7.0	2.4	3.5		18.1			0.8		4.1	
22	LST12-16bH	35.0	55.2	2.8	3.8	0.7	31.1	2.9		0.7	0.9	0.6	
23	LST12-16bT	35.0	55.5	2.9	4.6	0.7	30.0	2.7		0.5		1.3	
24	LST12-5	35.1	65.0	4.7	1.3		11.2	3.5		8.8	tr.	5.1	
25	LST12-BS-17	35.5	74.0	5.8	4.2		12.1			0.5		3.3	
26	LST12-BS-18	35.9	41.3	7.1	9.1	1.4	29.7	3.1		1.0	1.8	4.6	
27	LST12-6	37.0	48.1	2.8	0.5		0.6	tr.	1.0	46.7			
28	LST12-19b	38.0	36.4	1.4	tr.		8.5		1.0	51.9			
29	LST12-7	39.2	28.8	1.7	0.6		11.7		2.8	54.2			
30	LST12-20bH	39.8	39.9	1.3					5.4	53.1		tr.	
31	LST12-20bT	39.8	35.0	1.3					4.0	59.4		tr.	
32	LST12-8	40.6	26.8	2.1			5.7		1.0	64.3			
33	LST12-21bH	41.7	18.1	1.1					5.5	74.9		tr.	
34	LST12-21bT	41.7	27.7	1.2					4.8	66.0		tr.	
35	LST12-9	42.0	31.8	2.1			4.5		6.1	55.4			
36	LST12-10	42.2	22.7	1.0			tr.		2.8	73.2			
37	LST12-23b	44.4	18.0	1.4					1.9	78.3		tr.	
38	LST12-11	45.0	32.0	1.0	0.9		1.0		2.3	62.4		tr.	
39	LST12-24bH	46.2	7.8	0.6			tr.		3.0	88.0		tr.	
40	LST12-24bT	46.2	19.0	tr.	1.4		0.6		6.2	72.0		tr.	
41	LST12-24bVT	46.2	30.9				0.9		3.5	63.6		0.9	
42	LST12-12H	47.0	16.0	1.6			0.8		3.6	77.5		0.5	
43	LST12-12	47.0	15.9	1.3			0.6		2.6	79.1		0.5	
44	LST12-13H	48.0	14.2	2.2	tr.		0.8		2.6	79.5		0.5	
45	LST12-13	48.0	11.8	2.1	2.9		0.5		2.5	79.7		0.5	
46	LST12-25b	49.1	23.4	1.1	0.9		0.8		2.4	71.2		tr.	
47	LST12-14	50.2	18.0	1.2	tr.				5.5	74.3		tr.	
48	LST12-15H	51.5	22.7	1.7			1.6		3.4	70.2		tr.	
49	LST12-15T	51.5	15.2	1.1			0.8		5.1	77.5		tr.	
50	LST12-26bD	52.0	24.7				4.4		2.0	68.4		tr.	
51	LST12-26bL	52.0	15.1	tr.			3.8		2.0	78.3		tr.	
52	LST12-16	52.2	15.2	1.1			0.8		5.1	77.5		tr.	
53	LST12-BS-27	52.8	40.1	10.0	2.5		26.1			18.2		2.4	
54	LST12-17	53.8	9.9						0.7	89.2			
55	LST12-BS-28	53.8	38.1	17.2	4.2		29.7			5.2		4.9	
56	LST12-29b	54.3	12.5	0.6			tr.			86.1		tr.	
57	LST12-BS-30	54.6	28.3	10.6	3.6		19.5			31.7		5.9	
58	LST12-31b	55.2	7.3	1.1					0.5	90.2		tr.	
59	LST12-18	55.5	17.3		tr.		3.8		0.9	77.1		0.5	
60	LST12-BS-32	55.7	37.8	12.3	1.0		22.3			8.0		16.9	
61	LST12-19	56.1	12.1	1.2	1.2					84.2		1.1	
62	LST12-BS-33	56.5	52.5	11.9	1.6		30.7			1.9		0.9	
63	LST12-BS-34	57.3	39.8	20.9	1.5		35.4			0.9		1.0	
64	LST12-35b	57.5	15.3	1.9	1.0					81.4			
65	LST12-BS-36	58.1	28.1	37.7	2.5		30.2			0.9		0.6	
66	LST12-38b	59.5	4.7	tr.	0.7		2.6			91.3		tr.	
67	LST12-20	60.0	1.6	0.8					1.8	95.4			
68	LST12-BS-39	60.5	59.2	12.1	2.5		21.7			3.3		1.0	
69	LST12-BS-40	61.2	76.4	4.1	2.2		14.6			2.1		tr.	
70	LST12-21	62.0	13.2	1.8			4.8		1.4	78.4			
71	LST12-22	63.0	5.0	1.2			2.6		2.1	89.1			
72	LST12-42b	64.2	13.4	tr.			4.6		1.4	79.9		tr.	
73	LST12-23	65.0	6.8	1.0			2.2		4.1	85.0		0.9	
74	LST12-24H	66.0	4.5	1.8			1.7		7.7	83.9		tr.	
75	LST12-24T	66.0	25.2	1.3			4.5		0.7	68.2			
76	LST12-25	67.0	8.2	1.0			3.1		5.3	81.8		0.5	
77	LST12-26H	68.0	15.1	0.8	tr.		0.5		2.3	80.8		tr.	
78	LST12-26T	68.0	24.4	1.0			0.8		2.3	71.0		tr.	
79	LST12-26	68.0	1.5	tr.			2.5		5.9	89.5			
80	LST12-43b	69.1	2.9	0.7			3.8		3.8	88.2		0.5	
81	LST12-27	70.0	2.7	0.9			4.1		4.9	87.1		tr.	
82	LST12-28	71.0	4.1	tr.			1.5		14.3	79.5		tr.	
83	LST12-29	72.0	0.7				2.2		5.2	91.5			
84	LST12-30	73.0	5.2	0.5			1.7		2.9	89.3		tr.	
85	LST12-44b	74.0	0.9				3.2		5.3	9.0		tr.	

86	LST12-31	75.0	0.7				1.4		5.3	92.2			
87	LST12-32H	75.5	0.5	tr.			tr.		4.2	94.3		tr.	
88	LST12-32T	75.5	54.4						37.9	7.1		tr.	
89	LST12-33	76.0	1.0	tr.			2.7		5.3	89.6		tr.	0.8
90	LST12-34	77.0	2.4				1.4		2.5	91.2			2.4
91	LST12-45bG	78.8	0.5				4.4		0.6	91.2		0.5	2.5
92	LST12-45bP	78.8	1.0				3.8		5.8	89.1		tr.	
93	LST12-35	79.0	0.7	tr.			2.5		9.4	81.9		0.5	4.6
94	LST12-46bD	79.1	1.0				4.0		7.0	86.9		0.8	
95	LST12-46bS	79.1	9.2	1.1			10.7		1.9	73.1		3.4	tr.
96	LST12-36	80.0	3.0	0.6			2.9		8.9	83.8			0.6
97	LST12-37	81.0	1.5	tr.			2.4		6.8	87.5			1.1
98	LST12-47b	81.8	1.6	0.5			2.5		5.8	87.1			2.1
99	LST12-38	83.0	0.9	tr.			2.3		6.4	88.9			0.8
100	LST12-39	84.0	0.9	1.1			6.6		2.6	86.0			2.6
101	LST12-40	85.0	2.7	tr.			1.5		3.1	91.9			tr.
102	LST12-41	86.0		0.9			8.8		0.8	86.9			2.4
103	LST12-48b	86.9	1.5	0.7			2.6		2.2	92.4		tr.	
104	LST12-42	87.9	1.2	tr.			1.9		5.0	91.6			
105	LST12-43	88.0	2.5	tr.			2.6		3.2	91.0			
106	LST12-44	89.0	0.5				0.9		4.1	94.3			
107	LST12-45	90.0	0.9	tr.			2.2		3.8	89.1			3.4
108	LST12-46	91.0	1.3	0.5			2.4		1.2	94.3			
109	LST12-47	92.0	1.2	0.5			2.3		2.2	93.5			
110	LST12-49b	92.4	0.7				1.8		1.4	95.8			
111	LST12-50b	93.2	0.6				2.0		2.0	94.3		tr.	tr.
112	LST12-48	94.0	0.5	tr.			tr.		3.9	94.7			
113	LST12-49	95.0	1.1	0.8			0.8		3.1	93.6		0.6	
114	LST12-50	96.0	9.6	0.9			4.8		1.1	82.7		0.7	
115	LST12-51b	97.0	3.7	1.0			2.5		1.9	90.6		tr.	
116	LST12-51	97.0	7.6	1.0			6.3		0.6	83.8		0.5	
117	LST12-52b	98.0	3.7	1.0			2.5		1.9	90.6		tr.	
118	LST12-52	98.7	14.7	1.1			6.9		tr.	75.9		0.8	
119	LST12-53	99.0	6.6	1.1			4.6		1.7	85.3		0.5	
120	LST12-53bG	100.0	1.1	0.6			3.7		2.4	90.5	0.5	0.8	
121	LST12-53bP	100.0	1.5				6.0		2.4	89.3		0.5	
122	LST12-53bS	100.0	1.1	1.0	0.6		13.0		8.0	75.2		1.1	
123	LST12-54H	100.0	2.5	0.6			1.2		21.4	74.0			
124	LST12-54T	100.0	2.3	0.9			1.0		3.6	91.1		0.9	
125	LST12-55H	101.0	3.7	0.6			tr.		tr.	94.0			1.1
126	LST12-55T	101.0	2.0	1.2	tr.		2.9		1.7	91.6		tr.	
127	LST12-54b	101.9	2.7	1.0			4.6		1.7	89.3		0.5	
128	LST12-56	103.0	3.1	1.2			4.2		1.2	89.8		tr.	
129	LST12-57	104.0	1.8	0.6			2.2		1.1	93.9		tr.	
130	LST12-58	105.0	1.0	0.6			3.2		1.2	93.3		tr.	
131	LST12-55b	105.7	3.5	0.6			2.6		4.0	89.0		tr.	
132	LST12-59	106.9	1.5	tr.			1.8		6.0	9.0			
133	LST12-60	107.5	2.8	tr.			3.6		0.9	91.7		tr.	
134	LST12-61	108.0	1.3	1.2	tr.		3.7		5.2	87.6		0.5	
135	LST12-62	109.0	1.0	2.2	0.6		4.0		1.2	80.6		1.3	
136	LST12-63	110.0	7.6	1.3	tr.		3.5		1.6	85.5			
137	LST12-64	111.0	4.8	1.1			2.3		1.6	89.3		1.0	
138	LST12-65-1	112.1	4.5	1.2			2.6		2.2	88.9		0.7	
139	LST12-65-2	112.1	4.9	1.3			3.7		2.1	87.2		0.6	
140	LST12-66	113.0	15.5	1.7	tr.		14.1		0.8	67.4			
141	LST12-67	114.0	14.1	1.3	tr.		7.8		2.3	74.0		tr.	
142	LST12-68	115.0	5.1	1.5	tr.		4.8		10.8	77.2		tr.	
143	LST12-56b	116.5	9.2	2.1			19.1			68.8		tr.	
144	LST12-69	117.0	12.4	1.7	0.5		20.6	0.6		62.2		1.8	
145	LST12-57b	117.8	13.6	0.9	1.0		21.7		tr.	61.7		0.9	
146	LST12-70	119.0	17.3	1.6	1.2		16.8		1.1	62.1			
147	LST12-71	119.5	27.7	2.2	1.2		18.2		3.1	47.4			
148	LST12-72	120.0	15.7	3.9	2.0		23.2	1.9	0.8	52.3			
149	LST12-73	121.0	15.8	2.7	0.7		14.5	1.2	1.1	64.0			
150	LST12-58b	121.9	21.3	2.2	2.4		19.2		3.0	51.8			
151	LST12-74	123.0	13.0	4.2	1.5		31.5	1.8	0.7	46.7		tr.	
152	LST12-75	125.0	16.8	1.5	1.0		9.0	1.1	8.3	62.3			
153	LST12-76	126.0	14.1	12.5	11.7	4.6	48.4	2.7	0.6	4.8		0.5	
154	LST12-59b	126.0	24.2	12.8	16.0	4.5	28.9	3.1	0.6	8.9		tr.	
155	LST12-77	127.8	1.0	1.7	tr.		11.6			76.0			
156	LST12-60b	128.6	17.5	1.9	6.7		14.8	2.3		56.5			
157	LST12-60b	128.6	17.9	2.2	7.3		14.6	2.3		55.3			
158	LST12-78	128.8	14.2	6.3	9.3	2.1	23.5	1.6	0.5	42.2			
159	LST12-79	130.3	13.1	4.5	7.3	3.9	21.3	0.9	0.7	48.4			
160	LST12-61bD	131.4	14.2	7.3	12.9	1.7	26.1	1.3	0.7	35.7			
161	LST12-61bL	131.4	12.9	1.0	0.7		7.5	1.4		76.4			
162	LST12-80H	132.0	7.4	1.2			1.0			81.1			
163	LST12-80T	132.0	25.8	8.8	18.3		27.4	2.2	3.3	14.0			
164	LST12-62bD	132.1	19.6	5.2	11.1	1.3	14.9	1.0	0.8	46.1			
165	LST12-62bL	132.1	15.8	1.2	4.8		6.4	1.6		7.0			
166	LST12-81H	133.0	19.6	4.2	10.7		15.5	1.5	0.6	47.8			
167	LST12-81T	133.0	24.3	10.0	15.2	2.6	25.7	2.7	1.0	18.4			
168	LST12-63bD	134.0	23.2	15.2	21.1	1.8	30.4	2.4	1.9	3.7			
169	LST12-63bL	134.0	8.2	1.1			5.8	1.0		83.7			
170	LST12-82	135.0	17.3	1.4	3.7		7.7	1.1		68.7			
171	LST12-64bD	135.5	22.1	1.0	17.6	2.6	28.8	3.2	1.6	13.6			
172	LST12-64bL	135.5	5.1	1.0	0.7		3.7	0.8		87.9		0.6	
173	LST12-83	136.0	16.0	5.3	9.7	5.8	23.0	2.2	0.8	36.9			

174	LST12-65bD	136.2	28.2	12.9	19.8	1.5	26.2	3.0	3.4	4.9
175	LST12-65bL	136.2	13.3	1.4	tr.		6.1	0.5		78.1
176	LST12-66bD	136.9	30.4	11.4	22.0	2.5	25.0	3.4	3.5	1.8
177	LST12-66bL	136.9	13.5	0.8	0.9		6.8	1.3		76.5
178	LST12-84	137.0	25.6	8.2	15.9	1.8	25.8	2.3	2.6	17.6
179	LST12-85H	138.0	4.3	0.9	tr.		5.9	tr.		88.2
180	LST12-85T	138.0	19.7	7.1	12.2	3.2	29.5	3.0	2.8	22.1
181	LST12-86	138.7	23.8	4.5	17.7	2.2	16.9	2.7	7.0	25.0

Supplementary Table 2 .
Carbonate C-O isotope composition

No	Sample No	depth, m	δ13C(‰V-PDB)	δ18O(‰V-PDB)
1	LST12-2	25.9	-16.3	-11.4
2	LST12-BS-3	26.5	-15.8	-11.2
3	LST12-3	26.7	-14.6	-11.6
4	LST12-BS-5	27.4	-10.6	-9.5
5	LST12-4	29.0	-8.3	-7.9
6	LST12-BS-7	29.1	-7.9	-8.1
7	LST12-BS-8	30.3	1.8	-7.5
8	LST12-BS-9	30.8	-9.7	-10.2
9	LST12-BS-10	31.4	-5.8	-8.7
10	LST12-BS-11	31.8	-3.4	-7.6
11	LST12-12bH	32.5	-10.6	-11.1
12	LST12-12bT	32.5	-7.2	-10.5
13	LST12-16bT	35.0	-10.7	-11.1
14	LST12-5	35.1	-11.9	-12.7
15	LST12-6	37.0	-0.3	-7.1
16	LST12-19b	38.0	0.1	-7.0
17	LST12-7	39.2	0.4	-7.8
18	LST12-20bH	39.8	0.7	-9.5
19	LST12-20bT	39.8	0.7	-8.8
20	LST12-8	40.6	0.4	-7.4
21	LST12-21bH	41.7	-0.6	-9.5
22	LST12-9	42.0	-0.6	-9.0
23	LST12-10	42.2	0.6	-8.9
24	LST12-23b	44.4	0.4	-8.6
25	LST12-11	45.0	-0.1	-10.3
26	LST12-24bVT	46.2	0.2	-9.6
27	LST12-24bH	46.2	0.1	-9.0
28	LST12-24bT	46.2	0.4	-8.9
29	LST12-12	47.0	-1.2	-9.5
30	LST12-12H	47.0	-0.2	-9.2
31	LST12-13H	48.0	0.4	-9.0
32	LST12-13	48.0	0.0	-8.5
33	LST12-25b	49.1	0.2	-8.8
34	LST12-14	50.2	0.4	-8.5
35	LST12-15H	51.5	-0.5	-9.8
36	LST12-15T	51.5	-0.1	-8.9
37	LST12-26bL	52.0	0.3	-8.5
38	LST12-26bD	52.0	0.5	-7.8
39	LST12-16	52.2	0.2	-8.2
40	LST12-17	53.8	3.8	-4.3
41	LST12-29b	54.3	4.0	-4.6
42	LST12-31b	55.2	4.3	-4.4
43	LST12-18	55.5	3.4	-5.1
44	LST12-19	56.1	3.7	-4.5
45	LST12-35b	57.5	3.5	-4.7
46	LST12-38b	59.5	5.0	-4.8
47	LST12-20	60.0	6.0	-4.3
48	LST12-21	62.0	6.2	-5.1
49	LST12-22	63.0	6.2	-5.4
50	LST12-42b	64.2	5.5	-6.0
51	LST12-23	65.0	6.9	-6.2
52	LST12-24H	66.0	8.4	-8.2
53	LST12-24T	66.0	6.0	-7.3
54	LST12-25	67.0	7.5	-7.9
55	LST12-26	68.0	9.0	-8.3
56	LST12-43b	69.1	9.0	-6.1
57	LST12-27	70.0	7.0	-7.3
58	LST12-28	71.0	6.0	-8.5
59	LST12-29	72.0	7.7	-8.8
60	LST12-30	73.0	5.6	-9.5
61	LST12-44b	74.0	9.3	-7.0
62	LST12-31	75.0	6.5	-7.5
63	LST12-32H	75.5	8.7	-7.8
64	LST12-32T	75.5	2.9	-15.0
65	LST12-33	76.0	6.1	-6.9
66	LST12-34	77.0	6.6	-9.1
67	LST12-45bG	78.8	1.8	-9.0
68	LST12-45bP	78.8	8.3	-7.1
69	LST12-35	79.0	6.5	-8.1
70	LST12-46bD	79.1	7.8	-8.3
71	LST12-46bS	79.1	2.5	-7.1

72	LST12-36	80.0	7.7	-8.9
73	LST12-37	81.0	7.8	-7.7
74	LST12-47b	81.8	8.1	-7.0
75	LST12-38	83.0	7.6	-6.8
76	LST12-39	84.0	5.8	-7.2
77	LST12-40	85.0	8.0	-7.9
78	LST12-41	86.0	4.7	-8.5
79	LST12-48b	86.9	7.1	-9.0
80	LST12-42	87.9	6.7	-6.9
81	LST12-43	88.0	6.9	-6.6
82	LST12-44	89.0	7.8	-5.5
83	LST12-45	90.0	5.5	-7.8
84	LST12-46	91.0	7.9	-4.4
85	LST12-47	92.0	7.9	-4.7
86	LST12-49b	92.4	8.2	-4.6
87	LST12-50b	93.2	7.8	-4.9
88	LST12-48	94.0	4.5	-7.0
89	LST12-49	95.0	7.5	-5.0
90	LST12-50	96.0	6.8	-5.7
91	LST12-51b	97.0	5.7	-6.3
92	LST12-51	97.0	6.7	-5.5
93	LST12-52b	98.0	6.4	-5.7
94	LST12-52	98.7	5.6	-6.4
95	LST12-53	99.0	6.3	-6.0
96	LST12-53bG	100.0	4.4	-6.6
97	LST12-53bS	100.0	6.9	-5.8
98	LST12-53bP	100.0	7.5	-5.4
99	LST12-54T	100.0	7.0	-5.9
100	LST12-54H	100.0	1.6	-9.5
101	LST12-55T	101.0	7.5	-5.3
102	LST12-55H	101.0	1.3	-7.6
103	LST12-54b	101.9	7.5	-5.0
104	LST12-56	103.0	7.6	-5.3
105	LST12-57	104.0	3.4	-6.8
106	LST12-58	105.0	3.1	-7.7
107	LST12-55b	105.7	8.2	-6.6
108	LST12-59	106.9	7.9	-7.1
109	LST12-60	107.5	8.2	-5.1
110	LST12-61	108.0	7.4	-7.7
111	LST12-62	109.0	6.8	-6.2
112	LST12-63	110.0	6.2	-7.2
113	LST12-64	111.0	6.4	-5.9
114	LST12-65-1	112.1	7.7	-6.3
115	LST12-66	113.0	7.0	-6.4
116	LST12-67	114.0	5.7	-7.8
117	LST12-68	115.0	5.3	-7.6
118	LST12-56b	116.5	5.5	-7.6
119	LST12-69	117.0	4.7	-8.1
120	LST12-57b	117.8	4.6	-8.5
121	LST12-70	119.0	3.8	-9.5
122	LST12-71	119.5	3.8	-9.9
123	LST12-72	120.0	4.3	-9.0
124	LST12-73	121.0	3.8	-8.9
125	LST12-58b	121.9	5.0	-8.5
126	LST12-74	123.0	4.5	-7.8
127	LST12-75	125.0	3.9	-9.3
128	LST12-76	126.0	3.7	-9.5
129	LST12-77	127.8	7.1	-5.6
130	LST12-60b	128.6	7.1	-5.9
131	LST12-78	128.8	6.5	-6.1
132	LST12-79	130.3	6.1	-5.9
133	LST12-61bD	131.4	5.9	-6.8
134	LST12-61bL	131.4	7.3	-5.5
135	LST12-80H	132.0	6.9	-5.8
136	LST12-80T	132.0	4.0	-10.5
137	LST12-62bD	132.1	6.1	-6.9
138	LST12-62bL	132.1	6.6	-6.3
139	LST12-81T	133.0	3.9	-8.3
140	LST12-81H	133.0	4.3	-7.1
141	LST12-63bD	134.0	3.5	-11.3
142	LST12-63bL	134.0	7.3	-5.6
143	LST12-82	135.0	5.7	-6.4
144	LST12-64bD	135.5	4.5	-8.6
145	LST12-64bL	135.5	7.1	-5.5
146	LST12-83	136.0	5.3	-6.8

147	LST12-65bD	136.2	3.4	-12.2
148	LST12-65bL	136.2	7.1	-5.7
149	LST12-66bD	136.9	2.5	-14.8
150	LST12-66bL	136.9	7.2	-5.9
151	LST12-84	137.0	4.5	-9.2
152	LST12-85H	138.0	6.6	-5.9
153	LST12-85T	138.0	5.0	-7.9
154	LST12-86	138.7	3.9	-9.4

Supplementary Table 3A.

Organic carbon isotope composition, TOC

No	Sample code	Depth, m	δ13Corg (‰ V-PDB)	TOC, %
1	LST12-BS-1	24.58	-47.5	7.51
2	LST12-BS-2	25.15	-47.6	
3	LST12-BS-3	26.47	-38.2	0.69
4	LST12-BS-5	27.42	-47.1	4.56
5	LST12-BS-6	28.40	-47.0	3.82
6	LST12-4	29.00	-45.7	1.87
7	LST12-BS-7	29.12	-46.8	4.16
8	LST12-BS-8	30.32	-42.3	3.97
9	LST12-BS-9	30.77	-46.5	2.71
10	LST12-BS-10	31.37	-46.3	5.85
11	LST12-BS-11	31.77	-46.5	
12	LST12-BS-12C	32.53	-28.0	0.50
13	LST12-BS-13	33.18	-46.6	10.05
14	LST12-BS-14	34.23	-47.4	
15	LST12-BS-15	34.53	-46.6	
16	LST12-BS-16	35.03	-41.7	9.83
17	LST12-BS-17	35.48	-46.3	10.64
18	LST12-BS-18	35.88	-46.4	
19	LST12-BS-19	38.04	-42.3	0.24
20	LST12-7	39.20	-36.0	0.22
21	LST12-BS-20	39.75	-44.6	0.47
22	LST12-BS-21	41.68	-34.3	0.13
23	LST12-BS-22	44.35	-42.7	0.39
24	LST12-BS-23	46.16	-42.6	0.34
25	LST12-13D	48.00	-44.7	0.52
26	LST12-15D	51.50	-41.5	0.21
27	LST12-BS-26	51.95	-40.4	0.20
28	LST12-BS-27	52.75	-40.6	
29	LST12-17	53.80	-42.3	1.27
30	LST12-BS-28	53.83	-40.4	13.35
31	LST12-BS-30	54.59	-41.8	14.07
32	LST12-17	55.50	-39.3	0.80
33	LST12-BS-32	55.70	-41.3	
34	LST12-BS-33	56.52	-40.2	6.64
35	LST12-BS-34	57.28	-39.5	
36	LST12-BS-36	58.10	-39.9	5.03
37	LST12-20	60.00	-40.4	
38	LST12-BS-39	60.49	-37.8	7.45
39	LST12-BS-40	61.22	-39.9	5.49
40	LST12-BS-42	64.20	-40.4	
41	LST12-24D	66.00	-27.5	0.07
42	LST12-27	70.00	-36.1	
43	LST12-31	75.00	-31.0	0.08
44	LST12-45bG	78.75	-35.1	0.18
45	LST12-46bS	79.15	-33.7	0.48
46	LST12-39	84.00	-36.4	0.78
47	LST12-45	90.00	-33.3	0.14
48	LST12-48	94.00	-28.9	0.09
49	LST12-50	96.00	-34.2	0.11
50	LST12-53bG	99.99	-32.0	
51	LST12-56	103.00	-32.4	0.12
52	LST12-59	106.90	-31.7	0.50
53	LST12-62	109.00	-27.6	0.20
54	LST12-66	113.00	-31.1	0.25
55	LST12-57b	117.85	-29.1	0.15
56	LST12-73	121.00	-30.0	
57	LST12-76	126.00	-34.0	1.35
58	LST12-60b	128.56	-29.7	
59	LST12-61bL	131.44	-34.0	0.99
60	LST12-63bD	134.05	-30.8	
61	LST12-64bD	135.45	-31.0	
62	LST12-66bD	136.85	-36.4	0.27
63	LST12-85H	138.00	-29.0	

Supplementary Table 3B.

Organic carbon isotope composition of host rock and pyrobitumen veins

No	Sample code	Depth, m	δ13Corg (‰ V-PDB)	type
1	LST12-31B	75.00	-46.1	pyrobitumen
2	LST12-31C	75.00	-30.8	hostrock
3	LST12-34B	77.00	-45.9	pyrobitumen
4	LST12-34C	77.00	-33.5	hostrock
5	LST12-45bB	78.75	-46.5	pyrobitumen
6	LST12-45bC	78.75	-28.0	hostrock
7	LST12-35B	79.00	-46.1	pyrobitumen
8	LST12-35C	79.00	-26.2	hostrock
9	LST12-45B	90.00	-45.8	pyrobitumen
10	LST12-45C	90.00	-29.6	hostrock
11	LST12-46	91.00	-44.7	pyrobitumen
12	LST12-48B	94.00	-45.9	pyrobitumen
13	LST12-48C	94.00	-28.6	hostrock
14	LST12-59B	106.90	-45.2	pyrobitumen
15	LST12-59C	106.90	-31.7	hostrock

Supplementary Table 4.
Chemical composition, wt%

No.	Sample	depth, m	Al	Mn	Fe	Ca	Mg	Na	K	S	P
1	LST12-1	17.20	5.41	0.034	4.47	0.18	0.65	2.175	0.89	<0.04	0.025
2	LST12-BS-2	25.15	4.54	0.034	1.71	0.11	0.79	0.390	2.14	0.27	0.021
3	LST12-BS-5	27.42	4.64	0.036	1.58	0.14	0.70	0.521	2.24	0.57	0.016
4	LST12-4	29.00	4.48	0.434	2.13	2.10	1.14	0.521	1.79	0.78	0.021
5	LST12-BS-10	31.37	2.47	1.426	6.26	3.26	1.06	0.360	0.99	6.03	0.042
6	LST12-12bH	32.53	1.81	1.375	2.17	3.86	1.09	0.224	0.79	<0.04	0.536
7	LST12-BS-14	34.23	2.62	0.065	7.95	0.19	0.32	0.229	1.26	8.62	0.016
8	LST12-BS-18	35.88	2.77	0.016	1.40	0.23	0.45	0.276	1.47	0.87	0.015
9	LST12-6	37.00	0.85	0.802	1.81	10.80	4.36	0.078	0.37	<0.04	0.042
10	LST12-7	39.20	2.17	0.553	1.70	13.22	5.43	0.103	0.94	0.09	0.017
11	LST12-21bH	41.68	0.06	0.806	1.21	19.86	7.43	0.007	0.02	0.08	0.004
12	LST12-23b	44.35	0.29	1.054	1.18	17.01	7.28	0.010	0.12	<0.04	0.008
13	LST12-12	47.00	0.95	0.785	0.86	17.22	7.50	0.022	0.46	<0.04	0.024
14	LST12-25b	49.05	0.39	0.699	0.67	15.66	7.11	0.133	0.15	<0.04	0.015
15	LST12-15T	51.50	0.27	1.076	0.91	18.22	7.28	0.013	0.12	0.14	0.007
16	LST12-BS-27	52.75	4.24	0.079	2.29	3.70	2.57	0.177	2.66	2.16	0.035
17	LST12-BS-30	54.59	3.09	0.042	3.06	5.25	3.28	0.237	1.86	3.34	0.031
18	LST12-BS-32	55.70	3.25	0.019	9.68	1.90	1.21	0.102	2.23	>10.00	0.045
19	LST12-35b	57.54	0.43	0.290	1.44	16.91	7.83	0.167	0.19	<0.04	0.007
20	LST12-38b	59.52	0.27	0.140	1.11	19.59	9.15	0.071	0.10	<0.04	0.016
21	LST12-21	62.00	0.94	0.115	0.54	17.29	8.01	0.030	0.52	0.06	0.010
22	LST12-42b	64.20	0.70	0.062	0.53	18.51	8.31	0.020	0.38	<0.04	0.049
23	LST12-24T	66.00	0.75	0.059	0.41	15.03	7.67	0.016	0.38	<0.04	0.028
24	LST12-26T	68.00	0.34	0.023	0.24	22.89	9.39	0.012	0.16	0.10	0.037
25	LST12-27	70.00	0.74	0.050	0.49	21.27	9.29	0.016	0.36	0.19	0.167
26	LST12-29	72.00	0.33	0.094	0.57	22.60	9.83	0.010	0.15	0.04	0.061
27	LST12-44b	73.95	0.34	0.018	0.12	21.58	9.48	0.013	0.16	<0.04	0.028
28	LST12-32H	75.50	0.32	0.042	0.16	21.07	9.66	0.011	0.15	<0.04	0.031
29	LST12-34	77.00	0.33	0.033	0.30	20.71	9.12	0.015	0.17	0.08	0.573
30	LST12-35	79.00	0.44	0.036	0.39	23.13	8.43	0.017	0.21	0.12	0.786
31	LST12-37	81.00	0.30	0.010	0.10	21.50	9.90	0.014	0.15	<0.04	0.015
32	LST12-38	83.00	0.33	0.018	0.19	21.90	9.71	0.018	0.16	0.05	0.107
33	LST12-40	85.00	0.35	0.018	0.24	21.40	9.96	0.014	0.17	<0.04	0.037
34	LST12-48b	86.93	0.78	0.034	0.40	20.48	10.82	0.013	0.38	0.22	0.044
35	LST12-46	91.00	0.52	0.013	0.16	21.78	11.39	0.014	0.23	0.07	0.020
36	LST12-50b	93.17	0.40	0.018	0.28	21.84	10.15	0.015	0.19	0.11	0.037
37	LST12-49	95.00	0.48	0.019	0.38	21.59	9.67	0.020	0.24	0.24	0.056
38	LST12-51b	96.95	0.72	0.031	0.87	18.29	8.69	0.015	0.33	0.17	0.024
39	LST12-52b	97.95	0.70	0.026	0.50	20.64	9.44	0.018	0.32	0.06	0.028
40	LST12-53bG	99.99	1.30	0.039	0.93	19.78	8.93	0.034	0.61	0.56	0.164
41	LST12-54b	101.85	0.81	0.099	0.42	20.42	9.00	0.020	0.41	0.12	0.022
42	LST12-57	104.00	0.45	0.051	0.35	20.67	9.82	0.018	0.21	0.16	0.027
43	LST12-59	106.90	0.32	0.010	0.24	21.72	9.42	0.019	0.15	0.12	0.027
44	LST12-62	109.00	0.77	0.096	1.56	17.87	8.16	0.031	0.41	0.59	0.036
45	LST12-64	111.00	0.72	0.041	1.02	20.58	8.60	0.018	0.35	0.45	0.055
46	LST12-66	113.00	2.23	0.035	0.43	16.02	7.50	0.045	1.02	<0.04	0.062
47	LST12-68	115.00	1.17	0.032	0.50	21.36	8.04	0.039	0.51	<0.04	0.019
48	LST12-56b	116.49	3.11	0.023	0.82	15.86	7.38	0.082	1.39	0.21	0.041
49	LST12-70	119.00	2.94	0.025	1.18	14.02	6.36	0.149	1.32	<0.04	0.025
50	LST12-73	121.00	2.71	0.026	1.72	14.18	6.82	0.120	1.26	<0.04	0.023
51	LST12-74	123.00	5.22	0.023	1.72	11.16	5.88	0.232	2.46	<0.04	0.040
52	LST12-75	125.00	1.64	0.031	2.03	16.98	6.39	0.129	0.67	<0.04	0.020
53	LST12-77	127.80	2.03	0.031	0.65	15.58	8.37	0.067	0.85	0.06	0.014
54	LST12-79	130.30	4.73	0.048	1.66	11.08	6.22	0.686	2.15	<0.04	0.063
55	LST12-80H	132.00	1.79	0.040	1.00	17.25	9.29	0.060	0.81	0.09	0.011
56	LST12-63bD	134.05	7.44	0.008	1.52	2.01	1.33	1.649	3.04	<0.04	0.034
57	LST12-83	136.00	5.59	0.039	2.35	9.06	5.50	0.784	1.43	<0.04	0.049
58	LST12-66bL	136.85	1.40	0.037	1.00	16.88	8.95	0.086	0.58	<0.04	0.014
59	LST12-86	138.70	5.11	0.041	1.15	9.09	3.37	1.403	1.85	<0.04	0.042