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SACS Internal report

Note on the seismic data

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Summary

This report covers some practical aspects concerning the seismic data available in the SACS project.
In SACS1 the geological interpretation including the time-depth conversion has been determined on the ST98M11 seismic survey.
This interpretation is used in SACS2 as well, but now applied on a reprocessed part of the ST98M11 seismic data, referred to as the ST9407 survey, and to the 1999 time-lapse seismic survey ST9906. This implies, that any differences between the different surveys caused by processing should be taken into account.
The main conclusion of the analysis as described in this report is, that only a time-shift of 8 ms exists between the ST9407 and the ST98M11 surveys and that no polarity reversal exists between them as one might suspect at first sight.

Furthermore a description is given of the time-depth conversion model used within SACS and a seismic wavelet is given suitable for seismic modelling purposes.

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1 Introduction

Within the SACS project different seismic datasets are used. In the SACS1 project use has been made of the ST98M11 seismic survey, which has been shot in 1994 before injection of CO_2. In 1999 a new survey (time lapse survey) has been acquired and processed, referred to as the ST9906 survey. This survey covers partially the original ST98M11 survey. In order to be able to compare the time lapse seismic data with the ST98M11 survey the common part of the ST98M11 survey has been reprocessed. This reprocessed 1994 dataset is referred to as the ST9407 survey.
This report covers various aspects concerning these different seismic datasets including a comparison between the original ST98M11 seismic survey and the reprocessed ST9407 survey.

2 Time depth conversion

For the determination of the time-depth conversion relation use has been made of the markers in TVDSS (m) of the (semi-) vertical exploration wells in the area (block 15/9) and the corresponding seismic picks in TWT (ms) on the ST98M11 base survey. Table 1 gives an overview of the available data. Note that the wells 15/9-4, 15/9-14 and 15/9-18 have not been taken into account.

Table 1: Overview of the wells used for the determination of the TD conversion. The markers as identified on the logs in TVDSS (m) and the corresponding seismic picks in TWT (ms) have been indicated.

Well	RKB (m)	TWT (ms)					TVDSS (m)				
		Sea Floor	Top Plio	Intra Plio	Top Uts	Base Uts	Sea Floor	Top Plio	Intra Plio	Top Uts	Base Uts
15/12-2											
15/12-3	25						86	644	728	883	1106
15/8-1											
15/9-4	25	123	675	755	890	1149	102				
15/9-6	25	134	657	743	875	1101	111	581	650	809	1038
15/9-7	25	129	685	789	900	1140	107	602	722	831	1080
15/9-8	25	123	685	789	905	1155	103	602	712	838	1093
15/9-9	25	98	671	738	898	1133	83	591	667	831	1070
15/9-11	25	106	636	718	884	1131	88	548	656	818	1074
15/9-13	25	97	655	723	909	1092	81	576	659	844	1029
15/9-14	25						101				
15/9-15	25	98	706	770	928	1155	83	632	700	867	1104
15/9-16	25	106	656	729	887	1126	85	575	655	818	1065
15/9-17	22	106	606	724	890	1066	86	547	676	840	1023
15/9-18	23	110	682	773	906	1140	97				
15/9-A9											
15/9-A16											
15/9-A19											
15/9-A27											
15/9-A2T2											
15/9-C2H											

Table 2 shows the results of the time-depth conversion velocity model determined. For each marker the (constant) interval velocity from the layer above has been determined. The mean values over all the wells are taken as the final interval velocity model. The standard deviation shows the spread around the mean values for the interval velocities determined at the various wells. Note the high standard deviation for the interval velocities in the Pliocene intervals (intra Plio and Top Uts). This is essentially due to the uncertainty in the picked TWT of the intra Pliocene horizon.

With the determined interval velocity model both the TWT and the TVDSS have been calculated making use respectively of the well markers and of the picked horizons. The absolute and relative errors have been reported in Table 2. Note the relatively low errors at the Top Utsira and the Base Utsira.

Table 2: Results of the TD-conversion with a constant "interval velocity" model. The mean interval velocities determined from 9 exploration wells are reported

including their standard deviation. The uncertainties at the well locations using these mean interval velocities have been reported both in TVDSS and in TWT.

Vint (m/s)	1659	1785	2208	2077	2056					
St. Dev.	30	29	281	145	25					
	Vint (m/s) determined for each well									
15/9-6	1657	1797	1605	2409	2027					
15/9-7	1659	1781	2308	1964	2075					
15/9-8	1675	1776	2115	2172	2040					
15/9-9	1694	1773	2269	2050	2034					
15/9-11	1660	1736	2634	1952	2073					
15/9-13	1670	1774	2441	1989	2022					
15/9-15	1694	1806	2125	2114	2088					
15/9-16	1604	1782	2192	2063	2067					
15/9-17	1623	1844	2186	1976	2080					
	TWT (ms) from well markers in depth and Vint					**Depth (m) calculated from horizon picks and Vint**				
15/9-6	134	660	723	876	1099	111	578	673	810	1042
15/9-7	129	683	792	897	1139	107	603	718	833	1080
15/9-8	124	683	783	904	1152	102	604	719	839	1096
15/9-9	100	669	738	896	1128	81	593	667	833	1075
15/9-11	106	621	719	875	1124	88	561	652	824	1078
15/9-13	98	652	727	905	1085	80	579	654	847	1035
15/9-15	100	715	777	937	1168	81	624	695	859	1092
15/9-16	102	651	724	881	1121	88	579	660	824	1069
15/9-17	104	620	737	895	1073	88	534	665	837	1018
	Absolute error in TWT (ms)					**Absolute error in depth (m)**				
15/9-6	0	3	-20	1	-2	0.2	-2.9	23.0	1.1	4.4
15/9-7	0	-2	3	-3	-1	0.0	1.4	-3.8	2.5	0.2
15/9-8	1	-2	-6	-1	-3	-0.9	1.8	6.6	1.0	3.0
15/9-9	2	-2	0	-2	-5	-1.7	1.8	-0.2	1.9	4.5
15/9-11	0	-15	1	-9	-7	0.0	13.1	-4.4	6.0	3.9
15/9-13	1	-3	4	-4	-7	-0.5	2.6	-5.3	2.8	6.0
15/9-15	2	9	7	9	13	-1.7	-7.9	-5.3	-8.2	-11.8
15/9-16	-4	-5	-5	-6	-5	3.0	3.9	4.5	5.6	4.3
15/9-17	-2	14	13	5	7	2.0	-12.7	-11.4	-3.0	-5.1
	Relative error in TWT (%)					**Relative error in depth (%)**				
15/9-6	0	0	-3	0	0	0	-1	3	0	0
15/9-7	0	0	0	0	0	0	0	-1	0	0
15/9-8	1	0	-1	0	0	-1	0	1	0	0
15/9-9	2	0	0	0	0	-2	0	0	0	0
15/9-11	0	-2	0	-1	-1	0	2	-1	1	0
15/9-13	1	0	1	0	-1	-1	0	-1	0	1
15/9-15	2	1	1	1	1	-2	-1	-1	-1	-1
15/9-16	-3	-1	-1	-1	0	3	1	1	1	0
15/9-17	-2	2	2	1	1	2	-2	-2	0	-1

In Table 3 as an alternative the V_0-k velocity model has been determined, defined by the formula

$$V(Z) = V_0 + k\,Z \qquad (1)$$

with Z the depth and k the gradient.
This relation actually only makes sense for the intra-Pliocene shales (Top Utsira horizon) where most of the sonic logs show a clear gradient as well. For the other layers no gradient is observed or the data is insufficient to determine a reliable gradient.

From a practical point of view, no accuracy is added to the time-depth conversion using the V_0-k velocity model instead of constant interval velocities, as illustrated by the uncertainties reported in Table 3 compared to those in Table 2.

Generally as a “rule of thumb” it can be stated that each m uncertainty in TVDSS can be translated approximately to 1 ms in TWT.

Table 3: Results of the TD-conversion with the V_0-k model. Based on visual inspection of the log-data, only for the lower Pliocene shales (Top Uts horizon) this model makes sense. Note that the uncertainties for the V_0-k model and for the constant interval velocity model (Table 2) are comparable.

Markers	Sea Floor	Top Plio	Intra Plio	Top Uts	Base Uts	Sea Floor	Top Plio	Intra Plio	Top Uts	Base Uts
Vo (m/s)	1661	1758	3243	610	1832					
k (1/s)	-0.0388	0.0799	-1.6407	1.8793	0.2328					
	TWT (ms) from well markers in depth and Vo-k					**Absolute error in TWT (ms)**				
15/9-6	134	660	722	883	1106	0	3	-21	8	5
15/9-7	129	683	794	900	1142	0	-2	5	0	2
15/9-8	124	683	784	907	1154	1	-2	-5	2	-1
15/9-9	100	669	738	901	1134	2	-2	0	3	1
15/9-11	106	622	718	880	1130	0	-14	0	-4	-1
15/9-13	98	652	727	910	1091	1	-3	4	1	-1
15/9-15	100	715	778	938	1168	2	9	8	10	13
15/9-16	102	652	723	887	1128	-4	-4	-6	0	2
15/9-17	104	621	736	897	1076	-2	15	12	7	10

Figure 1 shows the TD-velocity log based on well 15/9-9 using constant interval velocities except for the lower Pliocene shale, where the V_0-k velocity model has been used. This “type log” is relatively representative for the observed velocity logs in block 15/9. Note that for the TD-conversions applied within the SACS project the V_0-k velocity model has not been used.

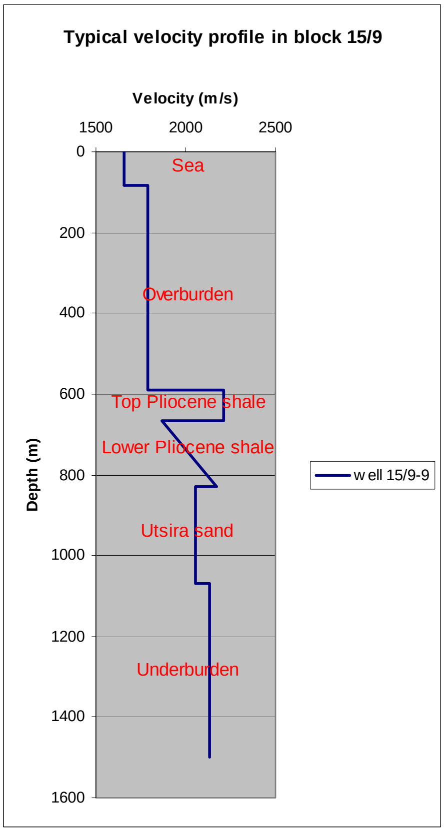


Figure 1: TD-velocity log based on well 15/9-9 using constant interval velocities except for the lower Pliocene shale, where the V_0-k velocity model has been used.

3 Polarity convention

The seismic data of the ST98M11 survey is assumed to be properly zero phase as a consequence of the processing sequence adopted by the seismic contractor.

In the header the polarity is mentioned as “SEG normal polarity (for zero phase data)”. This means that:

a positive sample = an increase in AI = a black or red peak

This convention has been corroborated by synthetic seismograms at various well locations. The consequences for the reflectors of interest within the SACS project are reported in Table 4.

Table 4: Consequences of the polarity convention of the ST98M11 seismic survey (zero-phase SEG normal polarity) for the key reflectors.

Seismic reflector	**Impedance contrast**	**Polarity seismic data**
Sea bottom	Increase	positive (red peak)
Top Pliocene	Increase	positive (red peak)
Intra Pliocene	Decrease	negative (blue trough)
Top Utsira sand	Decrease	negative (blue trough)
Base Utsira sand	Increase	positive (red peak)

The polarity of the reprocessed ST9407 seismic survey (and ST9906) is identical to the original ST98M11 survey.

4 Time-shift ST98M11 and ST9407 survey.

In the headers of the ST9407 survey and of the ST9906 survey Inlines vary from 1700 to 1988 and Xlines from 880 to 1460. These values are not conform to those of the original ST98M11 survey with a shift of 2000 both for the Inlines and Xlines. Therefore in the following the Inlines and Xlines of the ST9407 survey and of the ST9906 survey have been adapted by adding 2000 to each. More precisely the Inlines vary then from 3700 to 3988 and the Xlines from 2880 to 3460. An overview is given in table 5.

Table 5: Overview of the coordinates of the corner points of the different seismic surveys and of the injection point. Note, that the injection point is only a mean value, since the horizontal well has been perforated over an interval of approximately 30 m.

Survey	Inline	Crossline	UTM-X	UTM-Y
ST98M11	2200	2175	417817	6459721
	2200	4843	418314	6493067
	4094	4843	441986	6492714
	4094	2175	441490	6459368
ST9407	3700	2880	436696	6468253
	3700	3460	436804	6475502
	3988	2880	440296	6468200
	3988	3460	440404	6475449
ST9906	3700	2880	436696	6468253
	3700	3460	436804	6475502
	3988	2880	440296	6468200
	3988	3460	440404	6475449
Injection	3838	3123	438465	6471260

Furthermore a time shift of approximately 8 ms has been observed between the ST9407 survey and the original ST98M11 survey with the ST9407 survey “later” than the original survey (Figure 2).

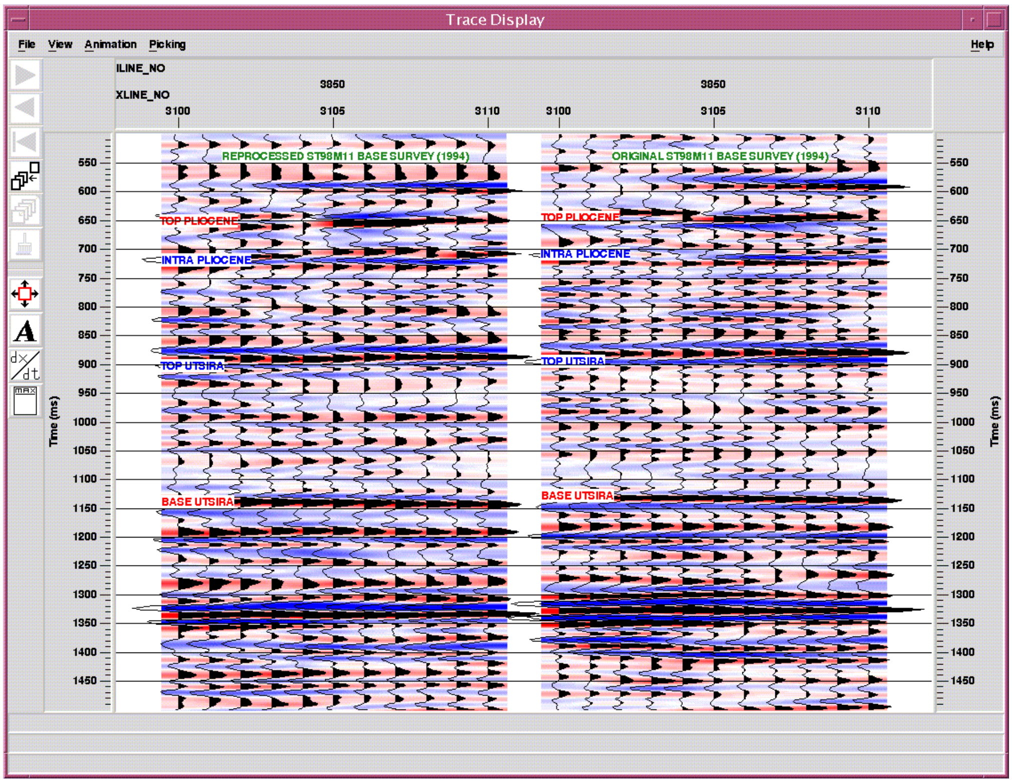


Figure 2: Time shift of approximately 8 ms between the 2 surveys with the reprocessed survey (left) "lower" than the original survey (right). Key horizons are indicated in the color of their polarity. The high energy reflections just above the Top Utsira sand are caused by tuning effects with the sand wedge reflections coming in from the east.

The time shift has been reported more accurately by taking the cross correlation of the two surveys and determining the average time lag. From the results on two Inlines (Figure 3) the average time lag has been estimated 8 ms with an uncertainty of 10%.

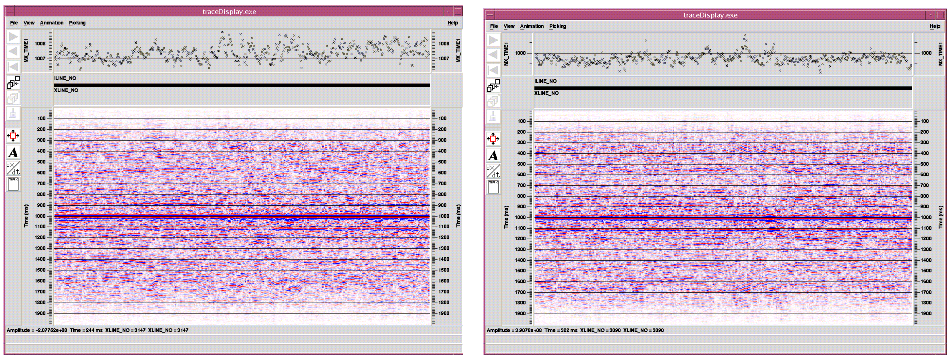
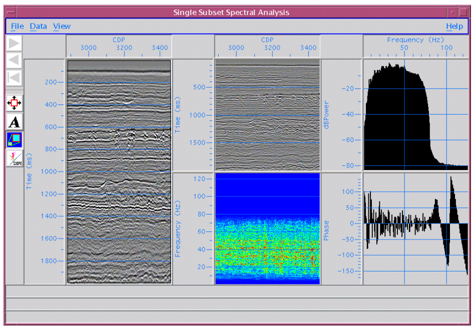


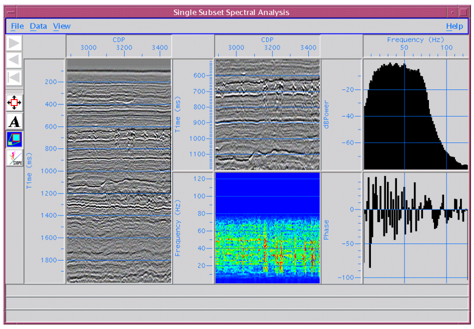
Figure 3: Cross correlation of the original ST98M11 and the reprocessed ST9407 survey on a trace by trace basis. Left corresponds to the cross correlation of the inlines 3800, right to the cross correlation of the inlines 3850. Note that the maximum of the cross correlation should be at time 1000 ms corresponding to a lag time of 0 ms. The time of the maximum correlation is reported above and corresponds approximately to 1008 ms (similar to a lag time of 8 ms). More precisely there is an average time shift of 8 ms between the 2 surveys with the reprocessed ST9407 data "later" than the ST98M11 survey (i.e. 800 ms on the original ST98M11 dataset corresponds to 808 ms on the ST9407 data).

5 Frequency content and estimated wavelet

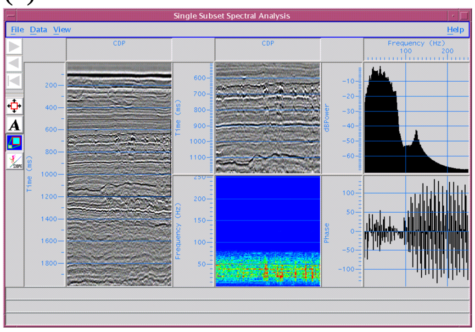
The frequency content of the original ST98M11 survey, of the ST9407 survey and of the time lapse ST9906 survey have been determined. The result is fairly constant showing a bandwidth from 10 to 70 Hz with a central peak frequency of 40 Hz. The results are visualised in Figure 4.



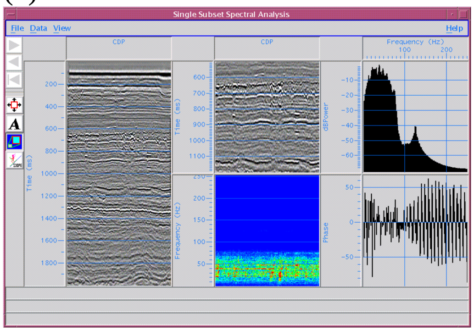
(a)



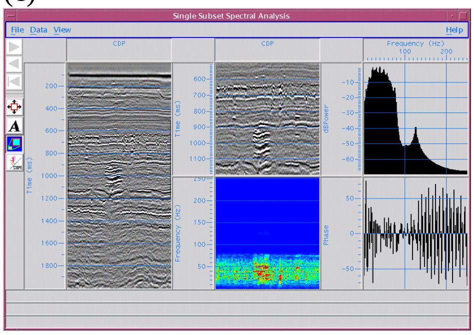
(b)



(c)



(d)



(e)

Figure 4: Frequency content of the original ST98M11 survey (a and b), of the reprocessed ST9407 survey (c and d) and of the ST9906 survey (e). Globally the frequency content is from 10 to 70 Hz with a peak frequency of 40 Hz for all surveys in the area of interest. (a) and (b) show the difference between a spectrum taken in a time window of 0 to 2000 ms (a) and of 500 to 1200 ms (b). The latter corresponds to the reservoir of interest. The differences are negligible. Figures (c) and (d) show the spatial variability of the spectrum with (c) taken from Inline 3800 and (d) from Inline 3850. Both spectra are

very similar. It appears that processing introduced an artefact at approximately 120 Hz. The ST9906 survey (e) has a comparable spectrum as well.

Based on the assumption of zero phase seismic data a wavelet has been estimated from the reprocessed ST9407 survey. This has been done at various Inlines in order to check the spatial variability of the estimated wavelet. The results show no significant changes, leading to an optimum mean wavelet. The results of the analysis are shown in Figure 5.

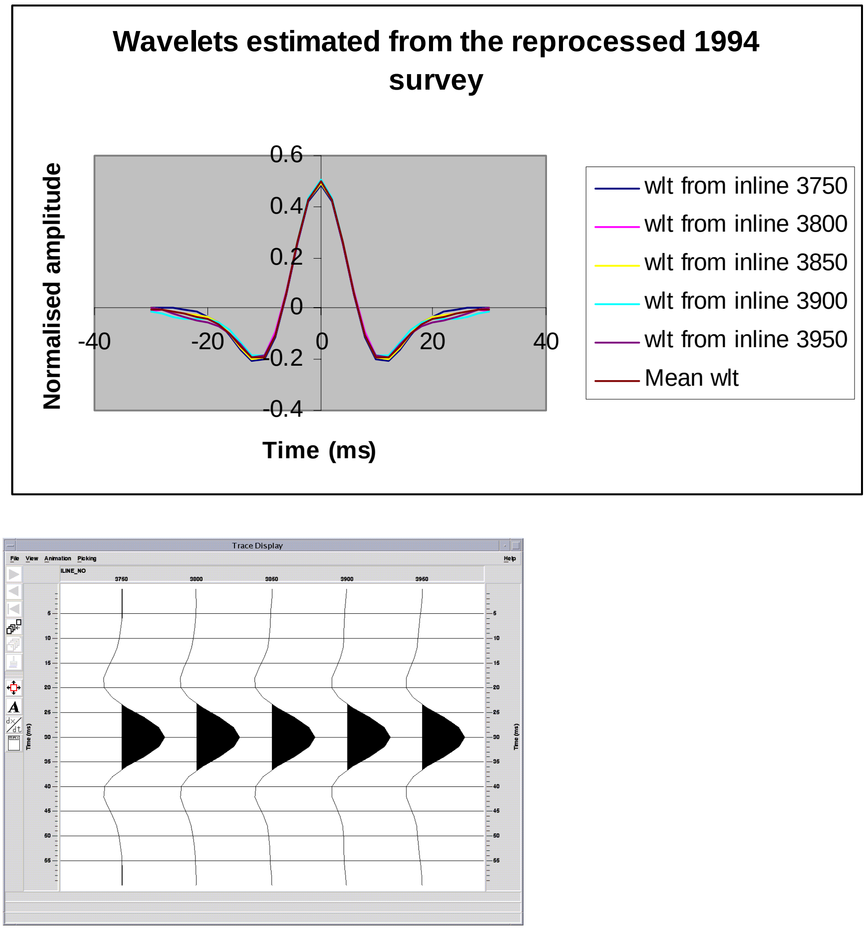


Figure 5: Zero-phase wavelets estimated from the reprocessed ST9407 seismic survey from different Inlines (3750 to 3950 with steps of 50) within the time window of 500 ms to 1200 ms.

Table 6 shows the numerical values of the estimated wavelet.

Table 6: Values normalised on the RMS value of the estimated mean wavelet from the reprocessed ST9407 survey.

Time (ms)	Mean wlt
-30	-0.00325
-28	-0.00630
-26	-0.01314
-24	-0.02213
-22	-0.03113
-20	-0.04089
-18	-0.05896
-16	-0.09577
-14	-0.14942
-12	-0.19390
-10	-0.18842
-8	-0.10333
-6	0.05888
-4	0.25856
-2	0.42804
0	0.49681
2	0.42804
4	0.25856
6	0.05888
8	-0.10333
10	-0.18842
12	-0.19390
14	-0.14942
16	-0.09577
18	-0.05896
20	-0.04089
22	-0.03113
24	-0.02213
26	-0.01314
28	-0.00630
30	-0.00325

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