"STRATFIT: AN EXCEL WORKBOOK FOR CORRELATION OF MULTIPLE STRATIGRAPHIC TRENDS "

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ABSTRACT

Correlation of distinct stratigraphic sequences is often critical to characterize evolution of sedimentary basins, as well as for exploration of georesources and for paleoenvironmental and paleoclimatic reconstructions. Stratigraphic correlation is usually based on signal matching between two or multiple proxies' records. Commonly, stratigraphers have to approach the correlation issue with time-consuming methods or specific software that may not be easily accessible or may not allow a full and direct control of the adopted procedure. In this work, we propose a new simple tool, which consists of a single Microsoft Excel workbook (that we named StratFit) organized in worksheets and allows an easy correlation of different stratigraphic curves and immediate visualization of the results. The correlation process is based on the FORECAST function and linear regression between subsequent couples of selected tie-points. The program is open source, user-friendly and allows a full control of the correlation process since all the computations are accessible for user's inspection and improvement. The StratFit workbook and the user manual are freely distributed and can be downloaded as supplementary material.

1. INTRODUCTION

The correlation of sedimentary stratigraphic trends from different basins and/or sections is a critical issue for all paleoenvironmental and paleoclimatic reconstructions, as well as for basin characterization in exploration and characterization of georesources. In particular, the reconstruction of changes in climate and/or environmental conditions at a regional or global scale in the geological past is generally accomplished by detailed studies of stratigraphic variations of suitable proxies in sedimentary sequences, whose tuning results in the set up of reference stack curves [e.g. global stack of oxygen isotope trends in marine sediments; Imbrie et al., 1984; Karner et al., 2002; Lisiecki and Raymo, 2005]. Stratigraphic correlation between distinct sedimentary sections and/or reference stack curves is usually based upon signal matching between two or multiple records of appropriate proxies.

This signal matching is an often difficult and tricky process, which requires multiple efforts to converge toward the most reliable solutions. Various attempts have been made in paleoclimate research to make correlation of stratigraphic trends easier. The different adopted approaches span from simple correlation by eye matching of stratigraphic features, which is often time-consuming, to automated correlation [Martinson et al., 1982; Waterman and Raymond, 1987] or dynamic programming techniques [Lisiecki and Lisiecki, 2002]. These latter techniques require the use of specific software and dedicated algorithms, which may not always be accessible or under the direct control of general users. In this manuscript, we propose a new user-friendly tool, the StratFit program consisting of a single Microsoft Excel workbook organized in worksheets, which allows an easy correlation of different stratigraphic curves and immediate visualization of the results.

The StratFit program was conceived to address the

needs related to the environmental magnetism analyses, as a tool to correlate two distinct stratigraphic sections by taking into account multiple trends in rock magnetic and paleomagnetic parameters [Sagnotti et al., 2011a,2011b].

Due to the extensive use and distribution of Excel, the operability of this software is guaranteed over the longer term for different operating systems (e.g., Mac Os X, Microsoft Windows). Moreover, the program is open source, user friendly and all the computations are accessible for user's inspection and improvement. During the correlation process the user can immediately check every change on the graphs and most importantly can take into proper account all useful available information (e.g., ^{14}C ages, lithological factors among others). Thus, the power of StratFit stems on the fact that this program allows an aware and interactive correlation of stratigraphic trends between two cores and not only an automatic passive match among peaks and troughs.

Lastly, the program has the following features, which may be valuable for various users:

   i) compatibility with nearly all computers;

  ii) easy input of data by "copy and paste", immediate visualization of the results and easy export of plots;

 iii) modular structure in distinct worksheets for each selected stratigraphic trend;

 iv) easy and prompt visualization of the effects of the adopted matching on multiple stratigraphic trends (up to 11 distinct stratigraphic trends in the released version, but easily expandable at wish);

  v) complete control of the whole workflow and possibility of implementation of the workbook by users.

In the following sections, we describe the software and its main features and applicability.

2. SOFTWARE DESCRIPTION

The released version of StratFit workbook is organized in 12 worksheets (Figure 1).

The green one is the "Data" worksheet, where the user introduces data for the two cores (one of which

considered as "master" and the other as the correlative core) and makes the choice of the tie-points for the correlation. The yellow sheets show the plots of the stratigraphic trends for each parameter, where the user can visualize and check the correlations.

The correlation process is based on the FORECAST function which implies a linear regression between subsequent couples of selected tie-points. This process results in the estimate of the equivalent depth of the correlated curve in the depth scale or age of the "master" curve.

In detail the Excel FORECAST function predicts a future point on a linear trend line fitted to a supplied set of x- and y- values.

The syntax of the function is:

$$FORECAST(\ x,\ known\_y's,\ known\_x's\ )$$

Where the arguments are: i) x, a numeric value for which you want to forecast a new y-value; known_y's, an array of known y-values; known_x's, an array of known x-values.

The known_y's and known_x's arrays correspond to pairs of coordinates defining consecutive tie-points linking the master and the correlative curves (i.e., depth y_B of correlative core B linked to a depth x_A of master core A).

2.1 DATA INPUT: GREEN WORKSHEET

In the Data worksheet (marked in green) the user enters the stratigraphic data of selected parameters (up to 11 distinct parameters) for both the master (core "A") and the correlative (core "B") cores and select pairs of tie-points for correlation.

The correlation process consists in matching the stratigraphic trends of up to 11 parameters from core B (listed in columns A to L, with headings marked in blue) with corresponding parameters from core A (listed columns T to AE, with headings marked in orange). This correlation is achieved by means of the tie-points, where a depth of B is associated with a depth of A.

In detail, the user should copy the data of reference stratigraphic trends of the "master core" in columns T to AE (Figure 2a). Columns A to L must be filled with
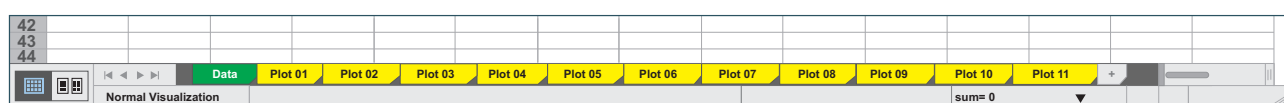
FIGURE 1. The StratFit Excel workbook is organized in 12 worksheets. The green one is the "Data" worksheet, where the user introduces data for the two cores and makes the choice of tie-point pairs for correlation. The yellow sheets show the plots of the stratigraphic trends for up to 11 distinct parameters, where the user can visualize and check the correlations resulting from the adopted tie-points.
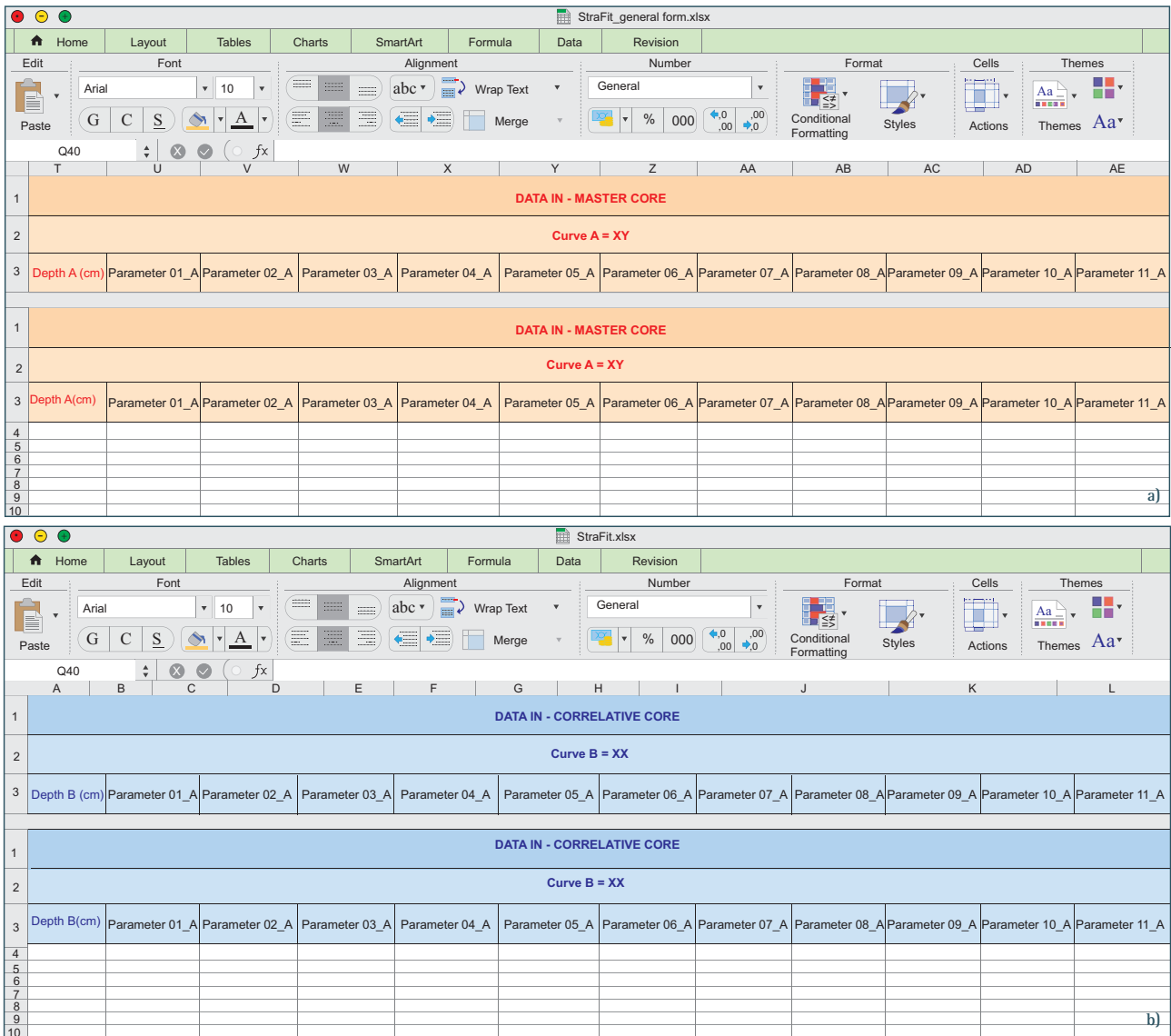
FIGURE 2. "Data" worksheet. a) Columns T to AE, where the user should list the data of reference stratigraphic trends of the "master core". b) Columns A to L, where the user should list data of the correlative core.

data of the correlative core (Figure 2b). Stratigraphic coordinates (depths, or ages) are listed in column T for the master core and in column A for the correlative core (Figure 2).

The columns P and Q are dedicated to the input of selected pairs of tie-points chosen by the user to correlate stratigraphic trends finding the best common depth (or age) (Figure 3a). The tie-points could be chosen either considering significant and coincident peaks and troughs of the curves or taking into account lithostratigraphic correlations and/or the information coming from other available stratigraphic constraints (e.g., ^{14}C ages). The common depth is computed in the column N according to the FORECAST function, resulting in a common depth by correlating each depth of core B to a corresponding depth of core A (i.e., in the stratigraphic framework of the master core). The stratigraphic framework (i.e., data in columns A and T) can also consist of ages rather than depths, of course.

Columns AX, AY, AZ and BA include formulas (based on the VLOOKUP, INDEX and MATCH functions) used to find the tie-point pairs on which apply the FORECAST function, for each x value of correlative core B. These columns are colored in red and should not be edited during the use of the software (Figure 3b).

Moreover, the Data worksheet includes a graph "Depth A vs Depth B", to the right of column AE. This graph allows to visualize the relative variation in the sedimentation rate resulting from the chosen tie-point pairs (Figure 3c).
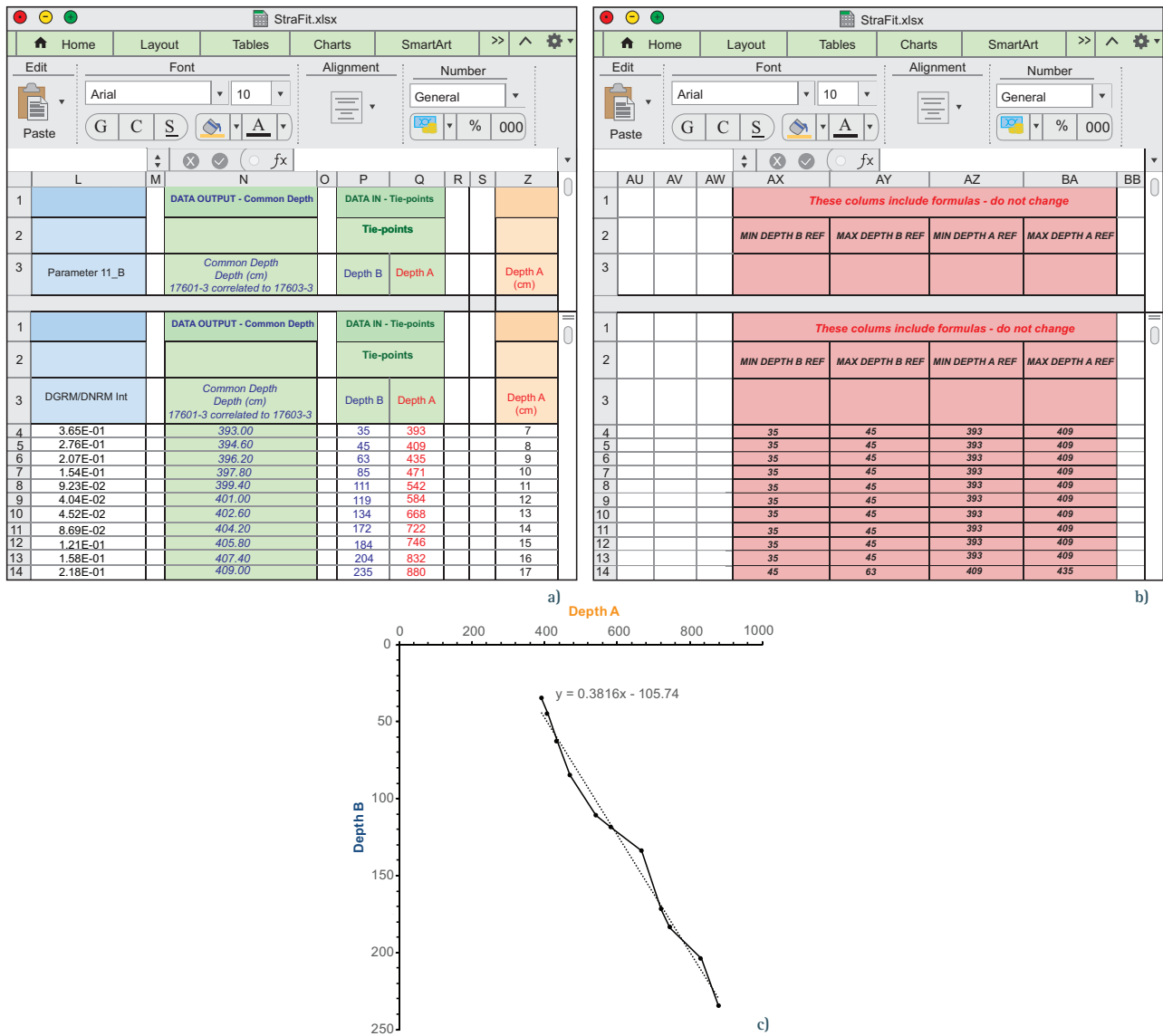
FIGURE 3. "Data" worksheet. a) Columns P and Q where the user should insert selected pairs of tie-points. The common depth is computed in column N according to the FORECAST function. b) Columns AX, AY, AZ and BA include formulas used to find the tie-point pairs that should be used to apply the FORECAST function, for each x value of correlative core B. These columns are colored in red and should not be edited during the use of the software. c) Graph of Depth A versus Depth B. This plot helps to visualise the effects of the selected tie-points on the relative changes in sedimentation rates between the two stratigraphic sequences.

## 2.2 GRAPHS OUTPUT: YELLOW WORKSHEET

Each worksheet marked in yellow refers to a specific parameter and shows plots of the stratigraphic trends. On each sheet four graphs are reported.

The graphs show i) the stratigraphic variation of the selected parameter in the stratigraphic coordinates (depth or age) of correlative core B (Figure 4a) ii) the stratigraphic variation of the selected parameter in the stratigraphic coordinates (depth or age) of master core A (Figure 4b); iii) the stratigraphic trend of the selected parameter in a common stratigraphic framework, after correlation of core B to core A, both as horizontal (Fig-ure 4c) and vertical (Figure 4d) plots. Observing the trends in the common stratigraphic framework, the effects of the selected tie-point pairs on the stratigraphic matching can be promptly and easily visualized.

3. WORKING EXAMPLE

The correlation process starts entering a first selection of a few tie-points, derived from lithological evidence or available radiometric data, if available, or by a starting assumption about sedimentation rates.
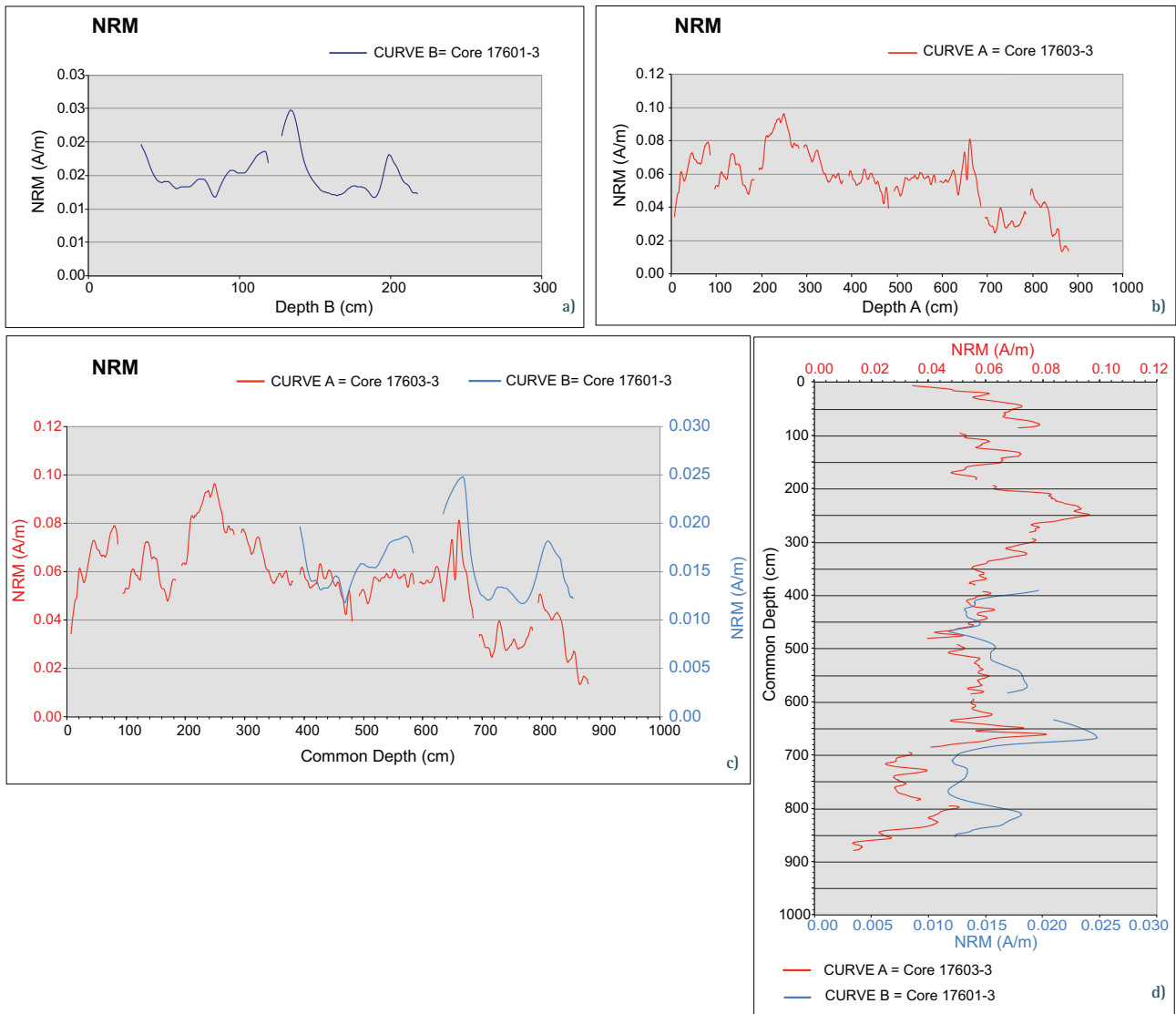
FIGURE 4. a) Stratigraphic variation of the Natural Remanent Magnetization (NRM) in the stratigraphic coordinates (depth or age) of core B. b) Stratigraphic variation of the NRM in the stratigraphic coordinates (depth or age) of the core A. c, d) Stratigraphic trends of the selected parameter in a common stratigraphic framework, after correlation of core B to core A, both as horizontal (c) and vertical (d) plots.

This process results in an initial visualization of the correlation effects on all the selected stratigraphic trends. Afterwards, the match between the distinct stratigraphic trends can be revised and improved by changing and adding tie-points that link directly the main peaks and troughs of distinct stratigraphic trends. This method is very fast and direct and it allows the user to check immediately and simultaneously the effects on the overall correlations among different parameters. In this way the user may identify the main tie-points for a core correlation that satisfy multiple parameters and stratigraphic trends.

Practically, first of all, the user has to paste the data in the specific columns, and then he has to insert some initial tie-points in columns P-Q. For the correct mode of operation of the worksheet the last tie-point of depth B has to be higher than the last value of the depth B. The user then can start an iterative process of improving correlation by changing or adding tie-point pairs.

The selection of tie-points correlating core B to core A has an effect on the relative changes in sedimentation rates. This effect can be visualized in the graph "Depth A *vs* Depth B" in the Data worksheet.
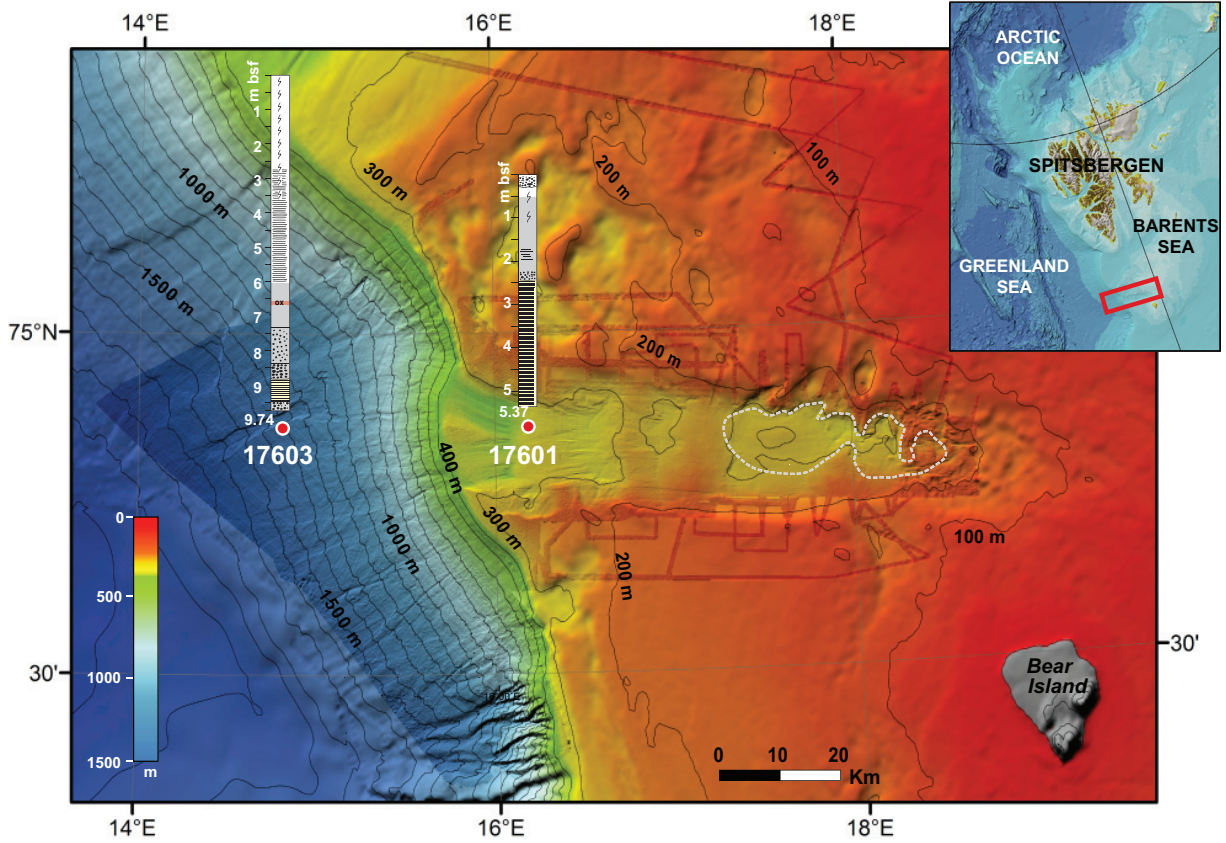
FIGURE 5. Bathymetric map of the Kveithola glacigenic trough with location of the cores here discussed.
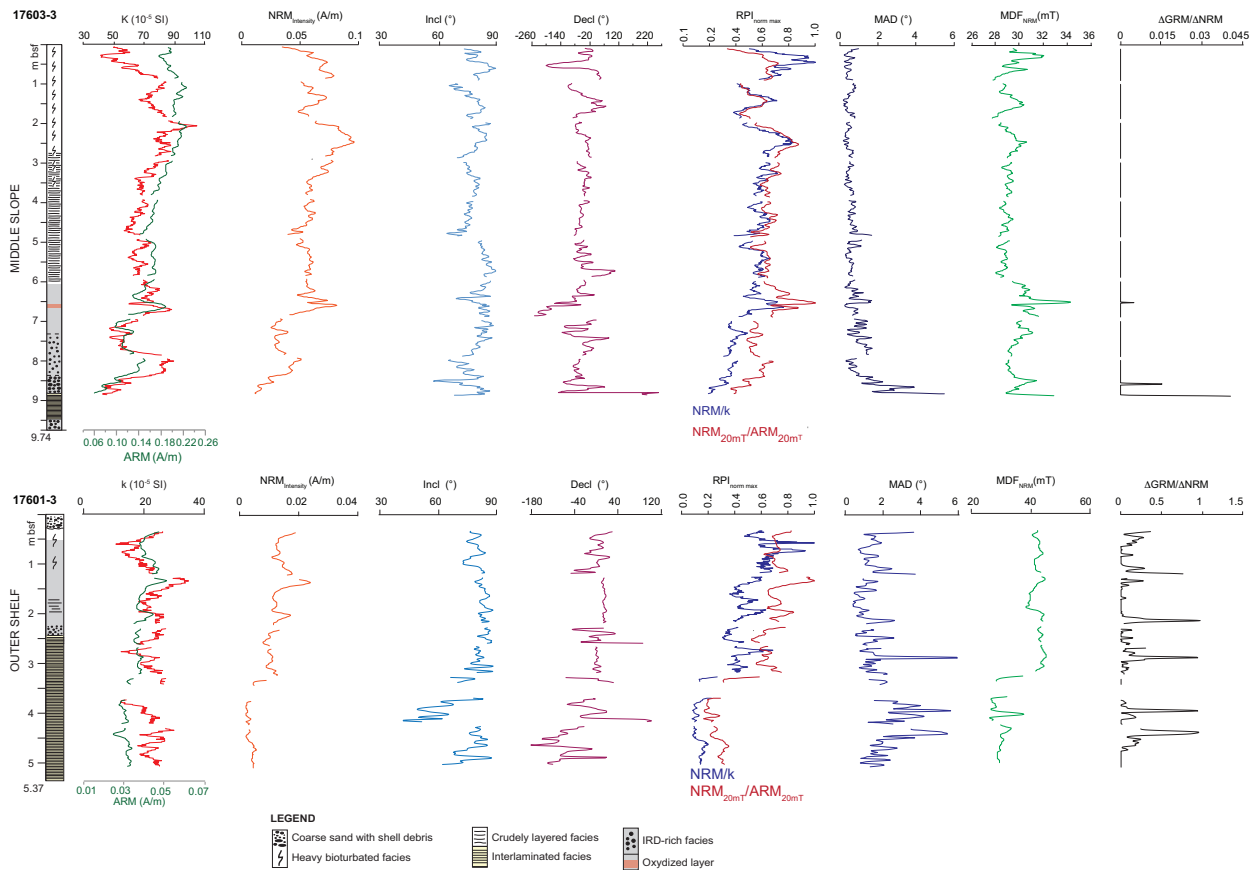

FIGURE 6. Stratigraphic trends of the rock magnetic and paleomagnetic parameters [Caricchi et al., 2018].
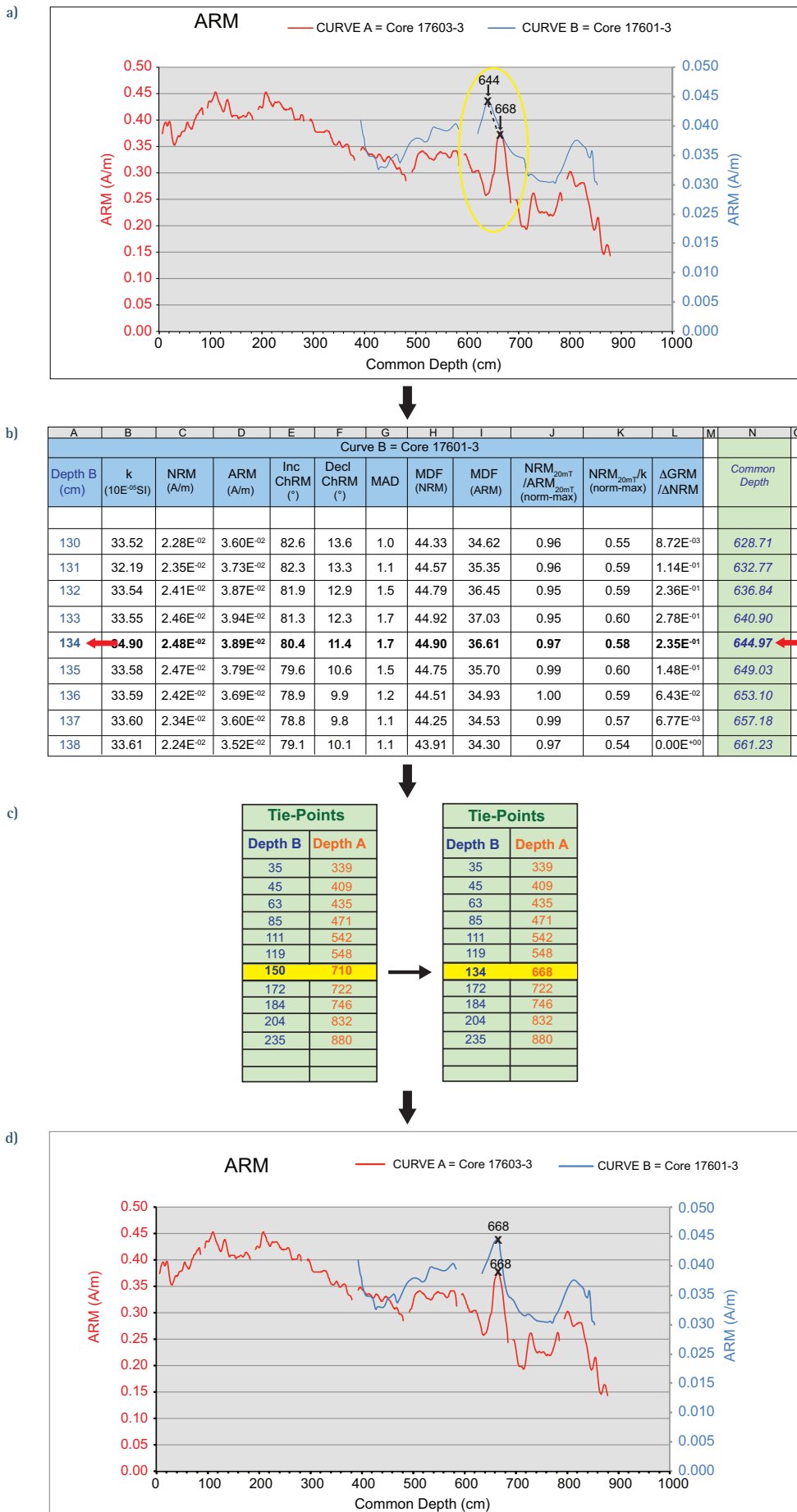
a)

b)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
							Curve B = Core 17601-3								
	Depth B (cm)	k (10E⁻⁰⁶SI)	NRM (A/m)	ARM (A/m)	Inc ChRM (°)	Decl ChRM (°)	MAD	MDF (NRM)	MDF (ARM)	NRM₂₀ₘₜ /ARM₂₀ₘₜ (norm-max)	NRM₂₀ₘₜ/k (norm-max)	ΔGRM /ΔNRM		Common Depth	
	130	33.52	2.28E⁻⁰²	3.60E⁻⁰²	82.6	13.6	1.0	44.33	34.62	0.96	0.55	8.72E⁻⁰³		628.71	
	131	32.19	2.35E⁻⁰²	3.73E⁻⁰²	82.3	13.3	1.1	44.57	35.35	0.96	0.59	1.14E⁻⁰¹		632.77	
	132	33.54	2.41E⁻⁰²	3.87E⁻⁰²	81.9	12.9	1.5	44.79	36.45	0.95	0.59	2.36E⁻⁰¹		636.84	
	133	33.55	2.46E⁻⁰²	3.94E⁻⁰²	81.3	12.3	1.7	44.92	37.03	0.95	0.60	2.78E⁻⁰¹		640.90	
	134	**34.90**	**2.48E⁻⁰²**	**3.89E⁻⁰²**	**80.4**	**11.4**	**1.7**	**44.90**	**36.61**	**0.97**	**0.58**	**2.35E⁻⁰¹**		**644.97**	
	135	33.58	2.47E⁻⁰²	3.79E⁻⁰²	79.6	10.6	1.5	44.75	35.70	0.99	0.60	1.48E⁻⁰¹		649.03	
	136	33.59	2.42E⁻⁰²	3.69E⁻⁰²	78.9	9.9	1.2	44.51	34.93	1.00	0.59	6.43E⁻⁰²		653.10	
	137	33.60	2.34E⁻⁰²	3.60E⁻⁰²	78.8	9.8	1.1	44.25	34.53	0.99	0.57	6.77E⁻⁰³		657.18	
	138	33.61	2.24E⁻⁰²	3.52E⁻⁰²	79.1	10.1	1.1	43.91	34.30	0.97	0.54	0.00E⁺⁰⁰		661.23	

c)

Tie-Points	
Depth B	**Depth A**
35	339
45	409
63	435
85	471
111	542
119	548
150	**710**
172	722
184	746
204	832
235	880

Tie-Points	
Depth B	**Depth A**
35	339
45	409
63	435
85	471
111	542
119	548
134	**668**
172	722
184	746
204	832
235	880

d)

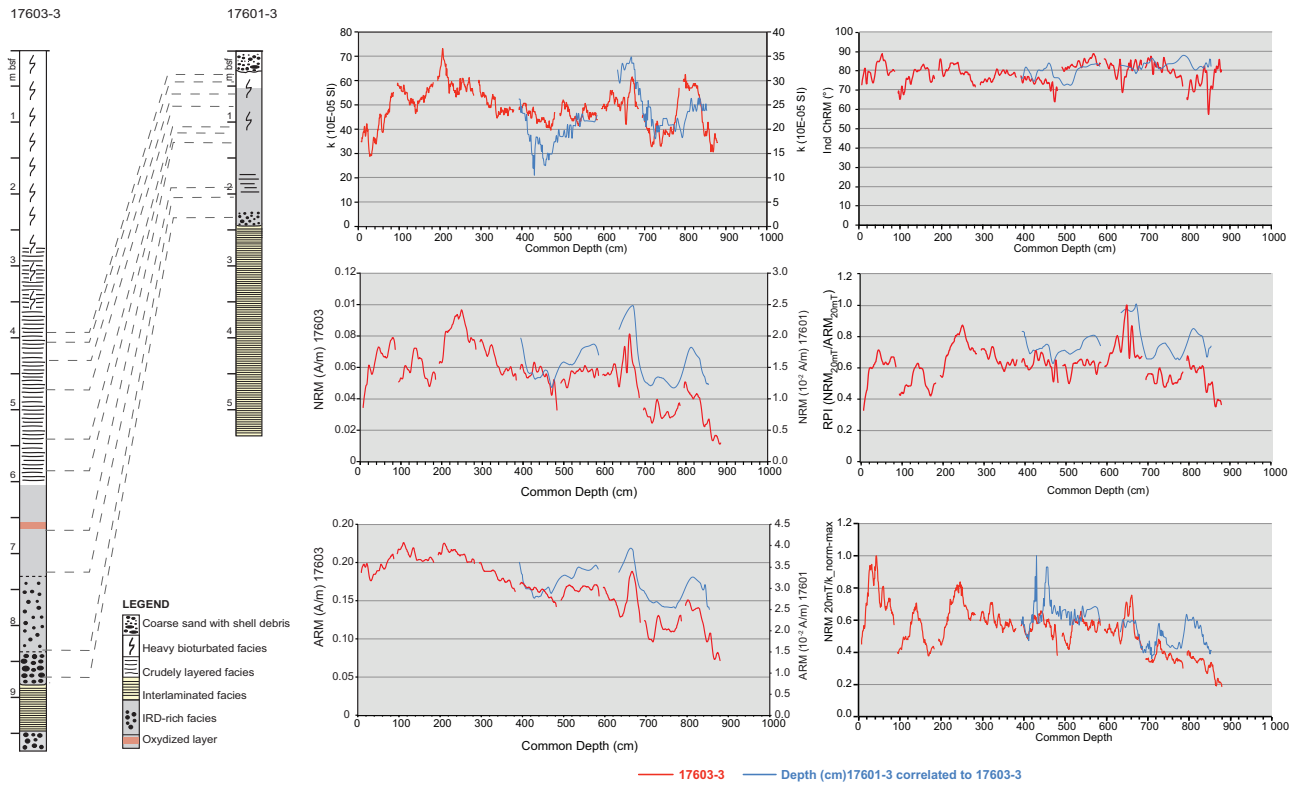**FIGURE 7.** Example of the tie-points choice and input.

FIGURE 8. Resulting correlations between selected rock magnetic parameters of the stratigraphic sequences from the Kveithola continental slope and outer shelf.

3.1 CASE STUDY

The example that we discuss refers to a study by Caricchi et al. [2018], carried out on sediment cores collected in the continental margin of the North-western Barents Sea, south of Svalbard (Figure 5). The work aimed to correlate the sedimentary sequences across the continental slope and shelf of the Kveithola glacigenic system, through paleomagnetic and rock magnetic analyses. The stratigraphic trends of the measured rock magnetic and paleomagnetic parameters of Core 17601-3 (correlative core "B", from the continental outer shelf) and Core 17603-3 (master Core "A", from the continental slope) are shown in Figure 6.

The initial tie-point pairs for core correlation were deduced from ^{14}C ages and lithostratigraphic constraints. Afterwards, the correlation has been refined through an iterative process aimed to improve the matching between peaks and troughs of paleomagnetic and rock magnetic parameters. To combine different peaks (or troughs) we adjusted the initial tie-points and added some additional tie-point pairs as in the example reported the Figure 7. Initial correlation implied, for example, the hypothesis that stratigraphic depth of

150 cm in the core B correlates to 710 cm in master core A. This assumption resulted in the plot shown in Figure 7a, referring to the stratigraphic trend of the ARM parameter, that is the intensity of the anhysteretic remanent magnetization, an artificial remanence produced by the simultaneous application of an alternating AF and a constant DC magnetic field, which depends on the concentration of ferrimagnetic minerals in the sediment. From this plot, it is clear that the ARM peak of Core B resulting at a common depth of 644 cm following the correlation under the initial constraints, matches closely the peak measured at 668 cm of depth in master Core A (Figure 7a). In this case the initial pair of tie-points was adjusted to improve the correlation and impose matching of the ARM peak observed in the two stratigraphic trends. To do this adjustment, the proper data were found in the "Data" worksheet, searching in column N (Common depth) the value closest to 644 cm and finding the corresponding depth in the column A (Depth B) (Figure 7b). In this case the value is 134 cm, thus the new tie-points pair was defined as 134 - 688, which implies that depth 134 cm in core B was now linked to depth 668 cm in master core A. Typing these values in the tie-point columns

(Figure 7c) it is possible to visualize directly the effects of the change in the ARM stratigraphic trends from the two cores (Figure 7d), as well as on all the other considered parameters, and then proceed with further analogous adjustments until the overall match is satisfactory.

This procedure allowed us to define a close correlation between slope and outer shelf sedimentary successions (Figure 8).

4. CONCLUSION

The StratFit workbook is designed to deal with the correlation between two distinct stratigraphic sections by taking into account multiple stratigraphic trends. The released software improves and simplifies the correlation process. StratFit may be valuable for various users for the following attributes:
- Compatibility with nearly all operating system;
- Easy input of data;
- Immediate visualization of the results;
- Easy export of plots;
- Modular structure in distinct worksheets for each selected stratigraphic trend;
- Easy and prompt visualization of the effects of the adopted matching on multiple stratigraphic trends;
- Full control of the whole workflow and possibility of implementation of the workbook by users.

The StratFit workbook and the User manual may be download as supplementary material.

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