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Automated Depth Shifting of Core Data: A Python-Based Approach

Mohammed Q. Abed Talib, Mohammed S. AL-Jawad
Department of Petroleum Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.
*Corresponding Author E-mail: m.murad1708@coeng.uobaghdad.edu.iq

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Abstract

In the field of petroleum exploration and reservoir analysis, the precise correlation between core data and log data is paramount. However, the presence of broken or incomplete core data due to core crumbling, stretch of logging tools cables, and information loss on cored depths poses a significant challenge, as it can hinder the accuracy of interpretations derived from log data also Manually shifting is both demanding and time-consuming, and its precision falls short when compared to the efficiency and accuracy of an automated shifting process. This paper introduces a novel Python-based solution for automatic depth shifting of core data to log data, aimed at enhancing the alignment and integration of these two essential datasets. By adopting the issue of incomplete core recovery, this approach offers a practical and efficient method to optimize data consistency and improve the quality of geological interpretations.

Keywords: Depth Shift, Python, Algorithm, Core Data, Well logs.

الازاحة التلقائية لأعماق بيانات اللباب باستخدام نهج قائم على لغة البايثو

الخلاصة

في مجال استكشاف النفط وتحليل المكامن، تُعدّ المواءمة الدقيقة بين بيانات اللباب وبيانات السجل البئري أمراً بالغ الأهمية. ومع ذلك، فإن وجود بيانات لباب مكسورة أو غير مكتملة نتيجة لتفتت اللباب، أو تمدد كابلات أدوات التسجيل، أو فقدان المعلومات المتعلقة بأعماق اللباب، يُشكّل تحدياً كبيراً يمكن أن يؤثر سلباً على دقة التفسيرات المستندة إلى بيانات السجل البئري. كما أن الإزاحة اليدوية لبيانات اللباب تُعدّ عملية مرهقة وتستغرق وقتاً طويلاً، فضلاً عن محدودية دقتها مقارنةً بكفاءة ودقة الإزاحة الآلية. يقدّم هذا البحث حلاً مبتكراً قائماً على لغة بايثون للإزاحة التلقائية لأعماق بيانات اللباب بما يتوافق مع بيانات السجل البئري، بهدف تحسين التوافق والتكامل بين هذين النوعين من البيانات الحيوية. ومن خلال معالجة مشكلة الاسترجاع غير الكامل للباب، يوفر هذا النهج طريقة عملية وفعالة لتحسين اتساق البيانات وتعزيز جودة التفسيرات الجيولوجية.

1. Introduction

In the discipline of geoscience and petrophysical interpretation, we frequently encounter a substantial degree of uncertainty in the data originating from various sources. Thus, our job is to reduce these uncertainties to the greatest extent possible. This reduction process is essential to

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construct an accurate and representative model of the reservoir under investigation. By reducing these uncertainties, we aim to enhance the reliability of our reservoir assessments.[1]

Core data serves as the cornerstone of hydrocarbon exploration and production, offering essential insights into subsurface geological formations and works as a calibration factor for data from other sources, e.g., well logs. It finds practical use in a range of studies, from petrophysical characterization [2], [3], performing geomechanics[4] and geochemistry studies among other. This ground truth data source is unique in its accuracy, surpassing what can be obtained from log data alone. While the coring process comes with substantial costs, its irreplaceable role in providing these valuable insights underscores its essential nature in the world of petroleum exploration and production.[5]

During the coring process, it is not uncommon to encounter challenges that hinder the complete recovery of the intended core interval. One significant challenge that has been prevalent in the reports of wells drilled during the 1980s and 1990s, as we experienced in our work, is the issue of low-core recovery. This means that not all of the targeted rock samples are successfully obtained.

In the field of geoscience and petroleum engineering, we've observed a growing trend in recent years toward automating calculations, driven by the twin objectives of minimizing human errors and expediting the calculation process. This automation not only enhances precision by reducing the risk of errors but also significantly cuts down the time required for complex computations.[6], [7].

In [8], two core shifting techniques are discussed: one based on intervals and the other involving point-to-point adjustments. Core shifting is a process that relies on numerous core readings being matched to corresponding log data, such as gamma ray, density, and sonic measurements, among others. The author utilized MATLAB software to implement the two techniques.

Reference [9] focuses on the process of shifting cores in offshore locations, particularly in the context of the oceanic crust. The criteria for selecting the optimal depth for core shifting are twofold: first, to identify new depths for as many core pieces as possible, and second, to minimize any disparities between core density and log density data.

It's important to highlight that many widely used commercial software packages, which combine core data and well logs, often lack automated calibration and depth-shifting features for core data. Instead, they typically offer a manual correction option, where users need to make

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adjustments themselves. This means that users have to perform these tasks manually, which can be time-consuming and potentially prone to errors [8].

Additionally, in the previously mentioned research papers, the focus was primarily on explaining the core data alignment algorithm, but there was no accompanying code provided for practical use by other researchers or professionals.

The research problem addressed in this paper centers on the need to bridge the gap between core data and log data within the field of petroleum exploration. While core data provides ground truth information that is critical for accurate reservoir assessments, its occasional incompleteness or inconsistency can pose challenges, including core crumbling, a stretch of logging tools cables, and information loss on cored depths. Ensuring the alignment and integration of core and log data is imperative for reliable geological interpretations.

The paper focuses on developing a Python-based solution for automatic depth shifting, to mitigate the impact of incomplete core data on the interpretation of log data, thus enhancing the overall accuracy and effectiveness of reservoir analysis.

In the sections that follow, we review the previous research in the literature and explore the methodology employed for the depth shifting of core data. We will outline the specific criteria we have used in this process. Additionally, the method's underlying code will be shared, offering a hands-on understanding of its implementation, and a demonstration of how the algorithm works will be presented with an example. This approach is designed to make the procedure clear and applicable in real-world scenarios.

2. Material and Methods

In the methodology section, we will discuss the specific methods employed in our algorithm and provide insights into how the algorithm functions.

2.1. Methods used

In our work, we chose to implement our code using the Python language. this choice is based on its widespread use, user-friendly nature, and the libraries it offers, including Pandas, Numpy, Scipy, and others, which greatly simplify data analysis and manipulation.

To determine the optimal depth, shift of core data, the Root Mean Square Error (RMSE) is used as the criterion. We opted for RMSE due to its ease of interpretation — it shares the same unit as the value under investigation. This stands in contrast to Mean Squared Error (MSE), which

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takes the square of the unit of the value being examined [10]. This choice simplifies the assessment process, making it more straightforward for effective interpretation and application.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Predicted_i - Actual_i)^2}{N}}$$

2.2. The algorithm of depth shifting:

The process of depth shifting unfolds as follows:

2.2.1 Input Full Log Data:

Commence by inputting the entire log data.

2.2.2. Input Core Data and Interval:

Proceed by providing the core data along with the core interval, specifying the top depth and bottom depth of the interval.

2.2.3 Calculate Iterations:

Determine the number of iterations where the start value is (0) and the end value is determined using the following equation:

$$End = D_{first\ point} - D_{top\ interval}$$

Where:

$End = End\ value\ of\ iteration$

$D_{first\ point} = first\ depth\ value\ of\ the\ first\ point\ of\ core\ data$

$D_{top\ interval} = top\ depth\ of\ core\ interval$

2.2.4 Apply Depth Shift:

Added the depth shift value to the depth of the core data.

2.2.5 Compute RMSE:

Calculate the Root Mean Square Error (RMSE) between the core data and log data. Given that log data are essentially a multitude of points plotted to resemble a line, and matching exact depths in core and log is rare, we employ linear interpolation. This method relies on the principle that any function appears linear when examined closely (Local Linearity).

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2.2.6 Update Best RMSE and Depth:

If the computed RMSE value is lower than the Best RMSE value, update both the Best RMSE value and the corresponding Best Depth shift value.

2.2.7 Increases depth shift:

The depth shift is increased by the following equation:

$$depth\ shift = depth\ shift + 0.01$$

2.2.8 Finalize Iterations:

Conclude the iterations, and display the Best RMSE value and Best Depth shift value on-screen. The newly shifted core data can be saved for further use.

The whole process is depicted in Fig. (***1***).

2.3. The algorithm features and limitations:

1- The algorithm is designed for an upward shift, addressing the gravitational effect on the core as it descends in the core barrel. It can be customized for other specific problems.

2- the algorithm code is designed to handle the shifting of a single core. However, it's considerately structured to accommodate multiple cores within the same well. This adaptability ensures that the code remains applicable and useful in situations where more than one core needs to be aligned with the same log data.

3- The algorithm code is written to be used with SI units, and the shifting value which is 0.01 meter, could be changed to any desired value by adjusting the code.

4- The algorithm shifts all the respective core data points with the same magnitude.

5- The input data must be in a comma-separated value (csv) format with two columns for both the log data and the core data where the first column is the depth and the other is the value needed to be shifted or the log data.

6- After the shifting process finishes the output of the process could be saved as (csv) file so it can be used.

7- The algorithm is designed to works on one log at a time so in case of having more than one log, the final log should be used for the shifting process. However, this could be also used to see which log is having the best approximation with the core data an example for that is when working with porosity data.

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3. Results and Discussion:

The developed Python-based algorithm for automated core-log depth shifting was rigorously validated through both synthetic and real-world case studies. This section presents the quantitative results and discusses their implications for petroleum engineering applications. Figure (1). Shows the algorithm flowchart.

3.1. Synthetic Data Validation

A controlled test was conducted using synthetically generated core data intentionally shifted by **3.99 meters** within the interval 3110–3120 m. The algorithm successfully identified an optimal shift of **3.98 meters**, achieving near-perfect alignment Figure (2). The RMSE between shifted core data and log readings reduced from an initial value of 0.178 to **0.021 post-shift**, confirming the algorithm's precision in ideal conditions. This result demonstrates the robustness of the RMSE minimization approach and the effectiveness of the linear interpolation method for reconciling discrete core measurements with continuous log data.

3.2. Field Application: X Field, Southern Iraq

The algorithm was further tested using real-world data from X field in southern Iraq, where the core data is detailed in Table (1). X field, located in southern Iraq, mainly comprises sandstone rocks within the formation of interest. The fourth core under investigation, with a recovery factor of 66% provide a good example to demonstrate the effectiveness of the algorithm. Applying the shifting algorithm to this specific core yielded a shift of 1.53 meters, as visually depicted in Fig. (**3**).

Table (1): Core porosity data of X Field.

Depth (M)	Porosity (decimal)	Depth (M)	Porosity (decimal)
3135.19	0.25	3137.25	0.267
3135.72	0.237	3137.88	0.254
3136.27	0.262	3140.88	0.249
3136.78	0.264		

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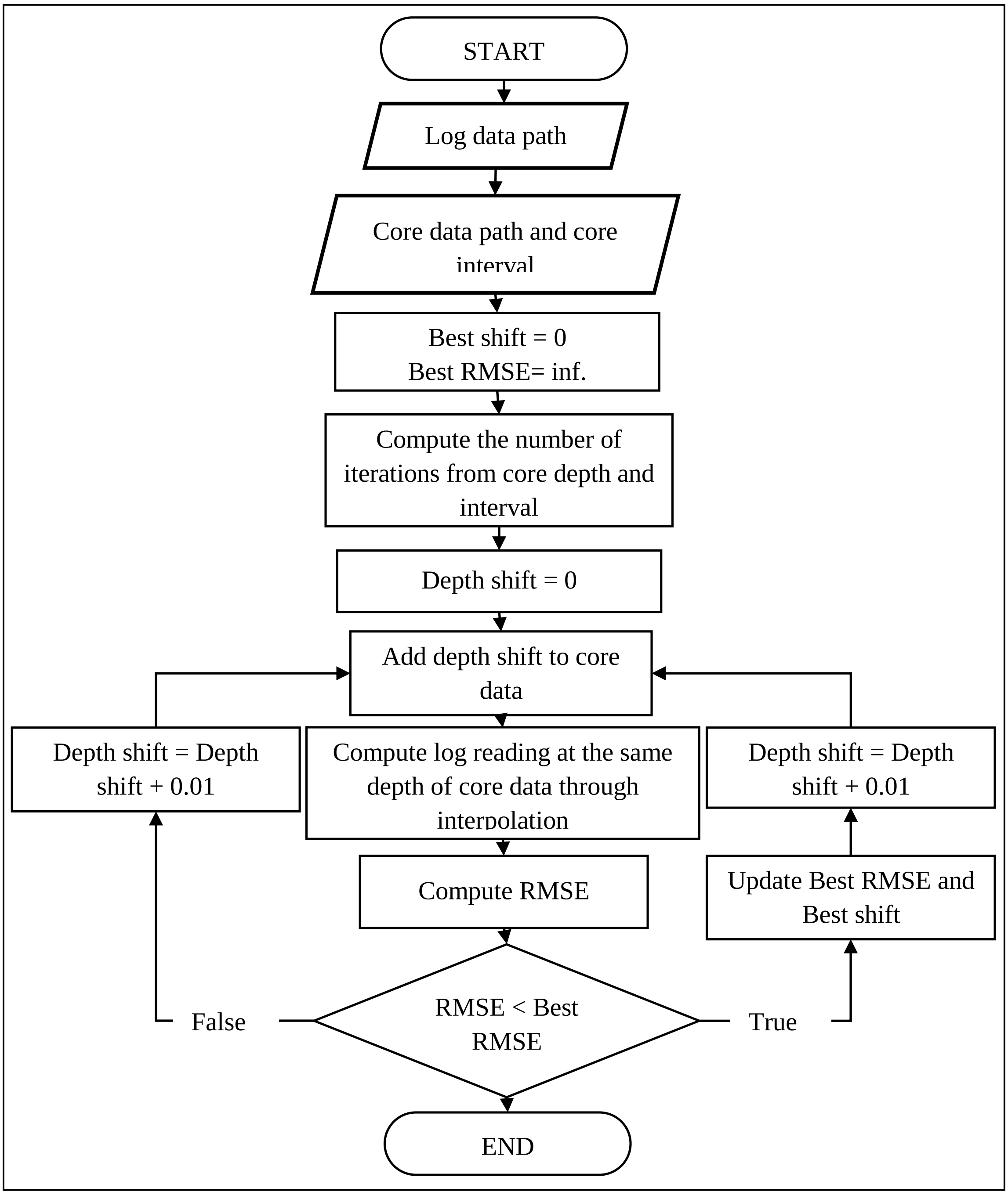

Fig. (1): Flowchart of the depth shift technique.

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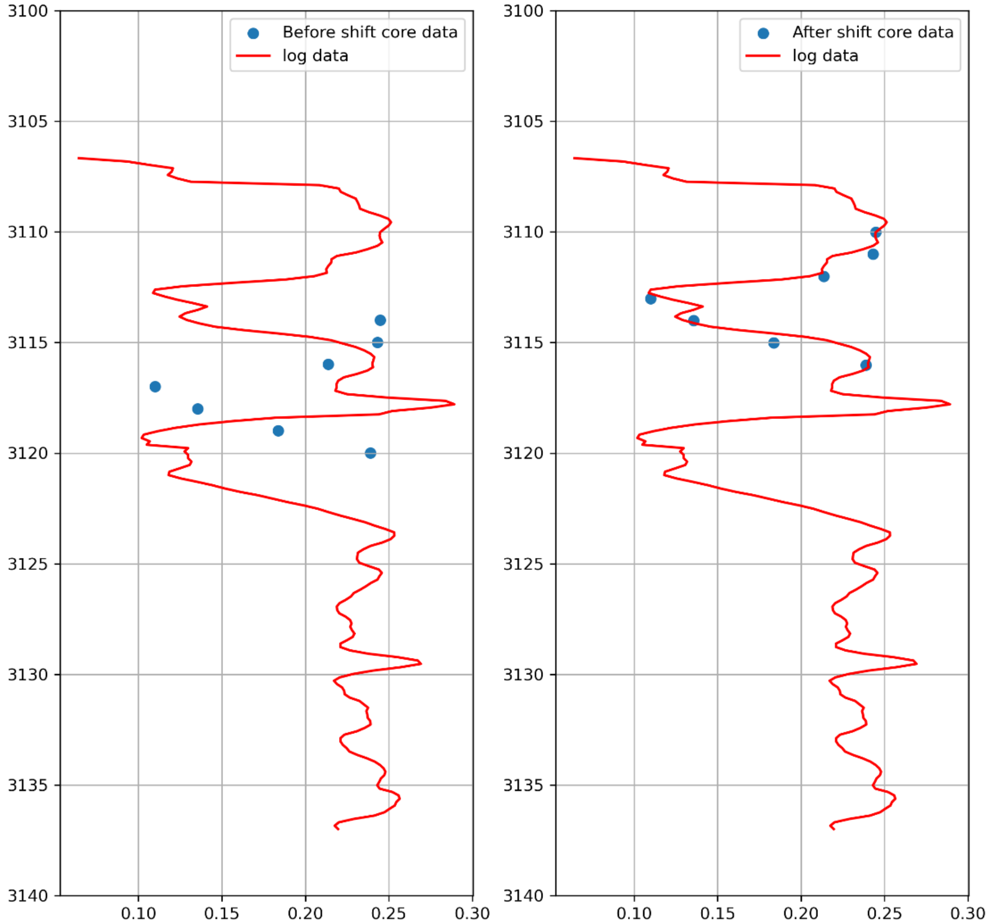

Fig. (2): The core data before and after applying the algorithm for the synthetic data.

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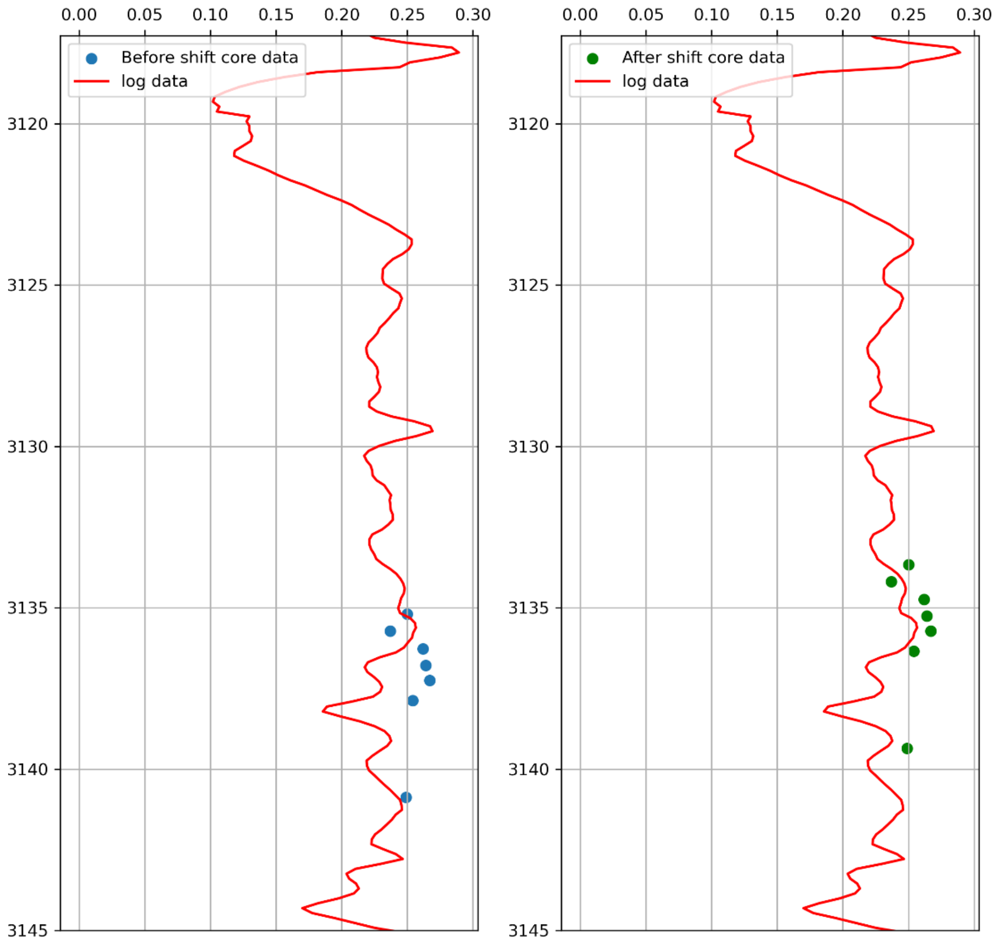

Fig. (3): The core data of Field X before and after applying the depth-shift algorithm.

4. Conclusions

- It’s important to emphasize that the code requires the following (Required libraries:) to be imported prior the use.
- Its demonstrated success in the (**Error! Reference source not found.**) section attests to its effective functionality.
- The algorithm is adaptable for integration into modern log interpretation software, offering a practical and efficient solution for aligning core and log data.
- This algorithm could be used not just for depth-shifting porosity but for any other measured petrophysical core property with its respective log.

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The algorithm code

Required libraries:

Code Box 1: Required Libraries

```
import numpy as np
from scipy.interpolate import interp1d
from sklearn.metrics import mean_squared_error
import pandas as pd
```

Code Box 2: The program code

```
class depth_shift_project:
  def __init__(self, log_data_path):
    log_data=pd.read_csv(log_data_path)
    self.data_set_2 = log_data.to_numpy()

  def core_data(self, core_data_path, top_interval, bottom_interval):
    data_core=pd.read_csv(core_data_path)
    self.data_set_1 = data_core.to_numpy()
    self.depth_min = top_interval
    self.depth_max = bottom_interval

  def save_new_data(self):
    new_core_data = self.data_set_1
    new_core_data[:,0] -= self.best_shift
    df_new_data = pd.DataFrame(new_core_data, columns=['Depth', 'porosity'])
    df_new_data.to_csv('shifted_data.csv',sep=',', index=False, encoding='utf-8')
```

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Code Box 2: continued

```
def optimum_depth(self):
    self.best_rmse = float('inf')
    self.best_shift = 0.0

    for depth_shift in np.arange(0.0, self.data_set_1[0, 0] - self.depth_min, 0.01):
  # Step 1: Create a copy of data set 1
        shifted_data_set_1 = self.data_set_1.copy()
  # Step 2: Add the depth shift to the copy data set
        shifted_data_set_1[:, 0] -= depth_shift
  # Step 3: Create a copy of data set 2 with manually set depth limits
        data_set_2_copy = self.data_set_2.copy()
        data_set_2_copy = data_set_2_copy[(data_set_2_copy[:, 0] >= self.depth_min) & (data_set_2_copy[:, 0] <= self.depth_max)]
  # Step 4: Create a copy of data set 2 matching the values and number of elements in shifted data set 1 (data set 3)
        f_interpolated = interp1d(data_set_2_copy[:, 0], data_set_2_copy[:, 1], bounds_error=False, fill_value="extrapolate")
        data_set_3 = np.column_stack((shifted_data_set_1[:, 0], f_interpolated(shifted_data_set_1[:, 0])))
  # Step 5: Calculate the RMSE between data set 1 and data set 3
        rmse = np.sqrt(mean_squared_error(shifted_data_set_1[:, 1], data_set_3[:, 1]))
  # Step 6: Save the value of RMSE and shift depth in a variable
        if rmse < self.best_rmse:
            self.best_rmse = rmse
            self.best_shift = depth_shift
    print("Optimal Depth Shift:", self.best_shift)
    print("Lowest RMSE:", self.best_rmse)
```

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Code Box 3: Example of How the code is used

```
# Inputs
core_path ='D:/project demo/core.csv'
log_path ='D:/project demo/log.csv'
top_interval=3110.0
bottom_interval=3120.0
# The code
well_1 = depth_shift_project(log_path)
well_1.core_data(core_path, top_interval, bottom_interval)
well_1.optimum_depth()
well_1.save_new_data()
```

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