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Review

Reconstruction of Land and Marine Features by Seismic and Surface Geomorphology Techniques

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Abstract: Seismic reflection utilizes sound waves transmitted into the subsurface, reflected at rock boundaries, and recorded at the surface. Interpretation of their travel times and amplitudes are the key for reconstructing various geomorphological features across geological time (e.g., reefs, dunes, and channels). Furthermore, the integration of surface geomorphology technique mapping, such as digital elevation models, with seismic geomorphology can increase land and marine feature modelling and reduce data uncertainty, as well. This paper presents an overview of seismic and surface geomorphology techniques and proposes an integrated workflow for better geological mapping, 3D surface imaging, and reconstruction. We intend to identify which techniques are more often used and which approaches are more appropriate for better output results. We noticed that an integration of surface and subsurface geomorphology techniques could be beneficial for society in landscape mapping, reservoir characterization, and city/regional planning.

Keywords: quantitative geomorphology; seismic geomorphology; seismic reflection; 3D imaging; earth surface reconstruction; remote sensing; aerial photogrammetry; geological mapping; integrated geomorphology

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Citation: Harishidayat, D.; Al-Shuhail, A.; Randazzo, G.; Lanza, S.; Muzirafuti, A. Reconstruction of Land and Marine Features by Seismic and Surface Geomorphology Techniques. *Appl. Sci.* **2022**, *12*, 9611. https://doi.org/10.3390/app12199611

Academic Editors: Ricardo Castedo and Fabrizio Balsamo

Received: 8 August 2022
Accepted: 22 September 2022
Published: 24 September 2022

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1. Introduction

Seismic reflection interpretation has existed for decades, beginning with a two-dimensional (2D) seismic reflection method and developing into a more intensive three-dimensional (3D) method. The primary components of seismic interpretation are seismic reflection data coupled with geologic depositional and tectonic models. These provide a framework for integrating borehole, microseismic, outcrop, and modern landscape analogue data that result in a realistic earth surface (geomorphology), subsurface reconstruction, and reservoir model [1–10]. Meanwhile, a proper understanding of seismic reflection data is a necessary precursor to successful interpretation [1,11–23]. The seismic reflection data utilize the transmission of a sound wave (triggered by an air gun, vibroseis, etc.) that propagates into the subsurface and is reflected to the surface when encountering an interface between two different rock properties, such as density and velocity. The reflected sound wave is recorded at the surface by receivers that measure its amplitude and arrival time (two-way travel time). Later, the recorded data are processed utilizing mathematical and signal processing techniques to produce an image of the subsurface. The seismic processing workflow could be different from one dataset to another depending on the geological conditions, target, processor, etc. The processing of seismic reflection data could be utilized in commercial software, e.g., Vista™ (Schlumberger), SeisSpace ProMax™ (Halliburton), Echos™ (Paradigm), Geovation™ (CGG), and many more. In addition, open source and free license software are also available, e.g., Madagascar, Seismic UNIX (Colorado School of Mines), SEPlib (University of Stanford), any many more.

The advancements in seismic acquisition and processing have provided significant improvements to the quality and resolution of seismic data; thus, the extraction of detailed geological information (and ultimately the development of a realistic 3D geological model) is becoming a reality. Plan-view images of the depositional elements and depositional systems (on a large scale) were provided by 3D seismic data, in which the morphology of these elements could be extracted from a seismic cube. Analysis of such images could significantly enhance predictions of the spatial and temporal distributions of subsurface lithology (reservoirs, sources, and seals), fluids, compartmentalization, and stratigraphic trapping capabilities. Furthermore, it can contribute to an enhanced understanding of process sedimentology, sequence stratigraphy, and tectonics [15,20,24–42].

Seismic geomorphology itself is the study of the subsurface using plan-view images from three-dimensional seismic data and aims to extract geomorphological, depositional, and other geologically significant features [12,15,20,27,29,43]. Seismic geomorphology, which depends on the interpretation of plan-view seismic images, is rapidly developing on several fronts, including [29]:

- Understanding the development of seascapes and landscapes in clastic and carbonate settings;
- Advances in workflows directed toward lithological prediction through the integration of seismic stratigraphy and seismic geomorphology;
- Revising and improving sequence stratigraphic models;
- Development of new and increasingly sophisticated analytical techniques.

Furthermore, the quantification of geomorphology from seismic reflection data features morphometric analysis of (for instance) sediment conduits that play an important role in the quantitative interpretation of sedimentary processes and paleoenvironments [39,44–53]. Morphometry includes:

- Height, defined as the vertical distance within a sediment conduit from its base to spill point;
- Top width, defined as the horizontal distance between two spill points;
- Base width, defined as the horizontal distance between two points in its floor;
- Cross-sectional area (CSA), defined as the area of a sediment conduit perpendicular to its axis;
- Aspect ratio, defined as the ratio between width and height of the sediment conduit's CSA;
- Sinuosity, defined as the ratio between a reference point and the sediment conduit's axis;
- Gradient, calculated from depth changes along the sediment conduit.

Moreover, surface geomorphology is the study of earth's physical land–marine surface features: its forms, processes, origin, development, and evolution that finally form a land–marine feature [54–61]. Nevertheless, shallow subsurface processes, other than surface and atmospherics processes, also play an important role on shaping the earth's land–marine forms (the evolution of topography). This subsurface process is mainly related to the geological processes including tectonics, volcanic activity, earthquakes, sedimentation, groundwater activity, sea-level changes, etc.

Furthermore, surface geomorphological data acquisition techniques, such as:

1. Quantitative geomorphology approaches have shown a great potential for identifying the location of geomorphological boundaries [62–64], the distance, surface, and the volume of geomorphological processes evolution [62,65–67].

2. Remote sensing techniques from space using radar sensors for supporting geomorphological interpretation of slow-moving coastal geohazards [68,69] or for monitoring subsurface deformation for interferometric analysis on a regional [70,71] or continental scale [72].

3. In situ and proxy geomorphological mapping techniques using unmanned aerial vehicles (UAV) photogrammetry, optical survey (for fine-scale topographic data), LIDAR

(Light Detection and Ranging), and any geographic information systems whose mapping provides reliable surface geomorphology data [73,74].

Apart from techniques and approaches used for data acquisition, surface geomorphology data processing algorithms and software have recently been developed and improved. Most of the earth observation satellite images available in Google Earth Engine (GEE) can be analyzed based on algorithms and a software interface of GEE Python application programming interface [75]. van Natijne et al. [76] used SAR images available in GEE to assess the potential of Interferometric Synthetic Aperture Radar (InSAR)-based deformation tracking; the authors demonstrated that the deformation could be detected on at least 91% of the global landslide-prone slopes. Other open-source software such as QGIS and SNAP desktop have been developed for the analysis of Optic and Radar images. The development of aerial photogrammetry technology has been accompanied by the launch of powerful Geographic Information System (GIS) software [77,78] such as Pix4D Mapper [79], Agisoft PhotoScan [80], and ArcMap for LiDAR and orthophoto quantitative analysis and geobody extraction.

Recent advances in technology (especially remote sensing) have provided a wider and larger area coverage of the earth's surface with high spatial resolution and free access (with term and conditions). In addition, near-surface or deep-surface acquisition data tools like seismic reflection data could provide results of deeper and wider areas (compared to other subsurface data) when it comes to depth of penetration (km scale) and lateral area (km^2 scale), respectively. Therefore, the aim of this study is to review seismic and surface geomorphology techniques already existing in the energy industry and academia and relate them to 3D earth subsurface imaging, reconstruction, sedimentary architecture, and geomorphological feature extraction from seismic reflection and surface geomorphology data. These techniques that are part of seismic geomorphology are grouped into the following main themes: seismic attributes, seismic sedimentology (including slicing techniques), volume rendering and geo-body extraction, and machine learning. In addition, the integration of seismic geomorphology and surface geomorphology techniques is proposed through an integrated surface and subsurface workflow toward a reliable 3D model of the earth and its geomorphology.

It is important to note that this research was conducted in the framework of Recovery Assistance for Cohesion and the Territories of Europe (REACT-EU) for Italian National Operational Program" PON Research and Innovation 2014-2020" projects on innovation and green issues (DM 1062/2021) granted in December 2021. The project was financed for green research project aiming at studying quantitative geomorphology from images. This research review intends to answer some questions such as where and which seismic and surface geomorphology techniques are used more often in identifying marine and land surface features? which approaches and technologies give better results? information in-dicating the possible combinations of technologies to obtain the best quality results and the ratios of different technologies were also analyzed. In addition, more details about the use of software for data processing are provided. In the future, the results of this research review will be based on during marine deep sediments identification for a new strategy of coastal protection in Sicily and for Italian coastal protection in general.

2. Review Method and Protocol

This review follows the guidelines of general literature review papers by Mohamed Shaffril et al. [81], Munn et al. [82], Snyder [83], and Xiao and Watson [84], where there are two main stages of the literature review method that have been implemented:

1. Planning the review: identifying why this review paper is needed and identification of research questions.
2. Conducting the review: selection of primary research, data extraction, and result reporting.

There are many studies about the reconstruction of past land and marine geomorphological features using seismic reflection data. However, there lacks an in-depth compilation of these techniques when they are combined with surface geomorphological techniques for present reconstruction (surface and shallow subsurface). Meanwhile, the utilization of other geophysical techniques (e.g., ground penetrating radar, gravity, magnetic, resistivity, electrical resistivity tomography, passive seismic, and seismic refraction) has indicated a significance increase during the last decade for present surface and shallow subsurface geomorphological reconstruction [85–87]. Furthermore, this compilation is important for research, as well as the industrial community to give a holistic view on seismic reflection and surface geomorphological techniques available for reconstructing the land and marine geomorphological features. Thus, the acquired data would be utilized in maximal and effective ways to be able to have better results and decrease the cost of production. Therefore, some research questions are:

- R.Q.1 What is the meaning of seismic geomorphology?
- R.Q.2 What are the available seismic geomorphology techniques?
- R.Q.3 How is the integration of seismic and surface geomorphology techniques accomplished?
- R.Q.4 Which technique is most often used and which approach gives better results?

This review utilizes research papers from the period of 2000 to 2022 in worldwide databases (Table 1). The paper-searching strategy included both manual and automatic search strategies to retrieve seismic geomorphology and surface geomorphology techniques from online databases including Scopus, Web of Science, GeoScienceWorld, and Multidisciplinary Digital Publishing Institute (MDPI). The manual search was based on the authors experience and expertise having worked with these techniques for many years, while the automatic search utilized specific keywords related to the research question. The keywords were "seismic geomorphology", "surface geomorphology technique", and "integrated seismic and surface geomorphology" with no filters on affiliation, country, or funding sponsor. However, the following filters were applied on the automatic searching strategy: subject area (earth science), document type (article and book chapter), and language (English).

Table 1. Summary of seismic and surface geomorphology research papers used in this review with the source of database.

Database	Keywords	Records	Total
Scopus	Seismic geomorphology	1197	1841
	Surface geomorphology technique	590	
	Integrated seismic and surface geomorphology	54	
Web of Sciences	Seismic geomorphology	1229	1926
	Surface geomorphology technique	613	
	Integrated seismic and surface geomorphology	58	
Geoscience World	Seismic geomorphology	3990	10,031
	Surface geomorphology technique	3498	
	Integrated seismic and surface geomorphology	2543	
Google Scholar	Seismic geomorphology	3480	19,040
	Surface geomorphology technique	12,700	
	Integrated seismic and surface geomorphology	2860	
MDPI	Seismic geomorphology	45	90
	Surface geomorphology technique	43	
	Integrated seismic and surface geomorphology	2	

The primary paper selection criterion utilized screening the titles and recognizable authors in seismic geomorphology and surface geomorphology techniques. This created restrictions to only select the original articles published in high-quality journals. In addition, duplicate results on the different keywords and irrelevance with keywords (e.g., only considering single keywords) were also removed. The secondary paper selection criterion was based on the following eligibility (exclusion and inclusion) criteria:

Inclusion Criteria:

- Research paper is published in peer-reviewed and good journal, represented in major indices with high impact factor.
- Research paper is accessible.
- Research paper has relevant content to seismic geomorphology and surface geomorphology techniques.

Exclusion Criteria:

- Research paper is published in non-peer-reviewed journal.
- Research paper is inaccessible.
- Research paper has no relevant content to seismic geomorphology and surface geomorphology techniques.

3. Seismic Attributes

A seismic attribute is any measure (quantitatively) of seismic data that helps interpreters to visually enhance or quantify features and geomorphologies of interpretive interest [88–95] (Figure 1). The development of seismic attributes has been integrated with seismic reflection interpretation and has roots extending back to the 1930s when geophysicists started to interpret (pick) travel-times with coherent reflections on recorded seismic field data [95].

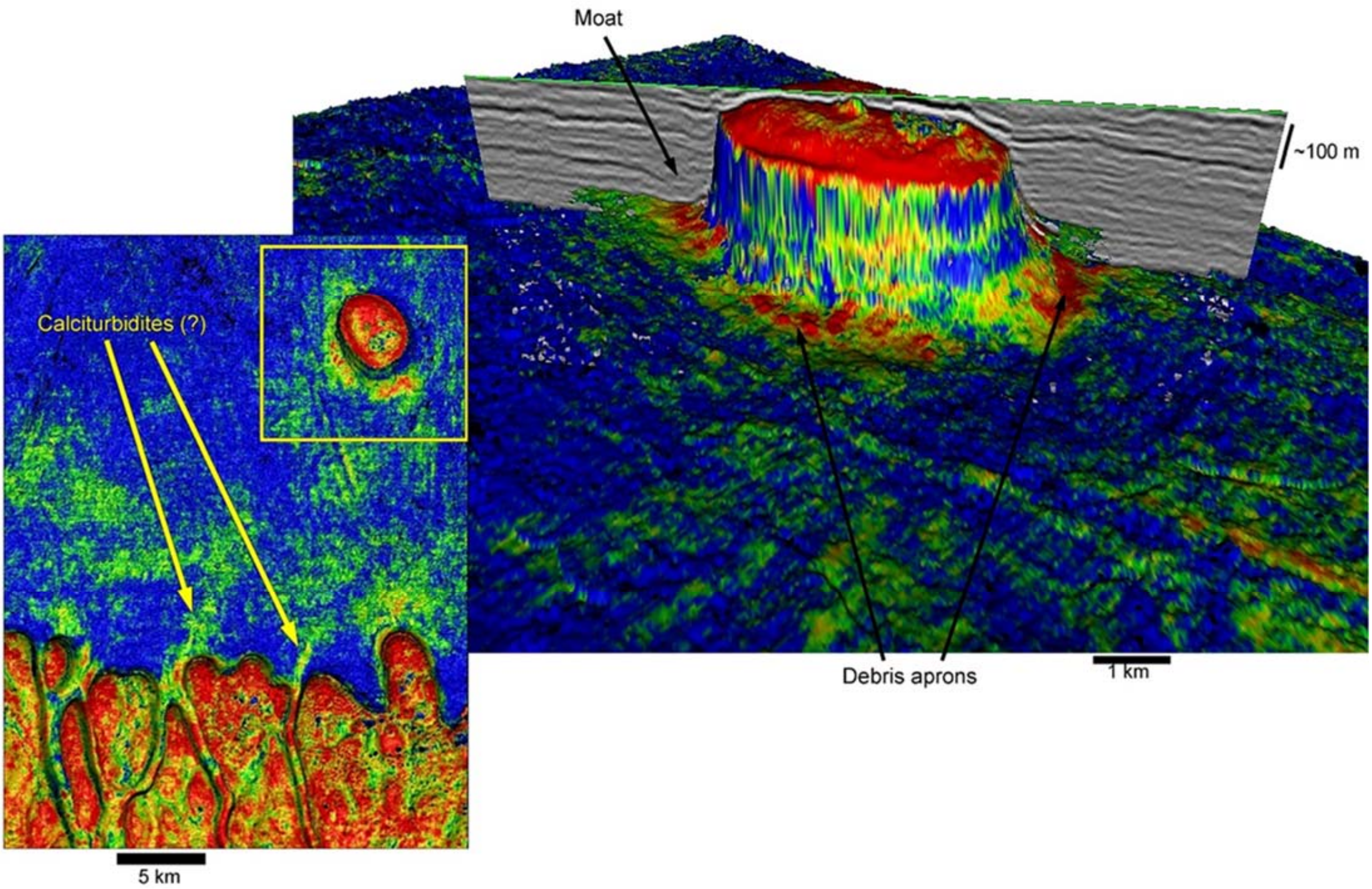

Figure 1. Seismic attributes (Root-Mean-Square Amplitude) showing geomorphology of the paleo-seabed reef features. Source: courtesy of Virtual Seismic Atlas (VSA), 2015 (www.seismicatlas.org, accessed on 1 January 2015). (VSA author: Henry Posamentier).

The development of seismic technology has always preceded the development of seismic attributes that could be a powerful tool in delineating geomorphological features, identifying prospective hydrocarbon volumes, etc. Hundreds of seismic attributes are in existence today, and this number will increase over time. Several seismic attributes duplicate one another, while others are obscure, unstable, or unreliable; other seismic attributes are purely mathematical quantities or are not truly attributes [89,95–97].

Many authors have different classifications of seismic attributes; for example, Taner [93] divided the attributes into the following two general categories: geometrical attributes and physical attributes. The purpose of geometrical attributes is to enhance the visibility of the geometrical characteristics or reflection characteristics of the seismic data such as seismic reflection configuration (including seismic facies), the reflection intensity of seismic events, dip, azimuth, and continuity. These geometrical attributes have the main function of enhancing seismic interpretation of sequence stratigraphy, seismic stratigraphy, fault, and structural interpretation. On the other hand, the physical attributes pertain to the physical parameters of the subsurface, and, therefore, relate to lithology and pore fluids (reservoir characterization). These include instantaneous phase, correlation coefficient, instantaneous frequency, (attributes derived from analytical seismic traces), interval velocity, amplitude versus offset, and normal moveout (attributes derived from pre-stack data).

Brown [90] classified seismic attributes using a tree structure in which time, amplitude, frequency, and attenuation were the main branches that further branched out into post-stack and pre-stack categories with horizon and window mediums. Time attributes are very useful on providing faults and structural geological information; these include residual, dip azimuth and magnitude, curvature, edge, illumination, coherence, semblance, covariance, trace difference, etc. Amplitude attributes work very well on enhancing stratigraphic interpretation and reservoir information, including amplitude versus offset, reflection amplitude, relative impedance, reflection strength, amplitude ratio, root-mean-square (RMS) amplitude, average energy, variance of amplitude, maximum amplitude, etc. Frequency attributes are very useful for identifying and extracting reservoir information (e.g., sandstone reservoir with gas); these include instantaneous frequency, time derivative frequency, spectral decomposition, arc length, dominant frequency, etc. Lastly, attenuation attributes could help us in identifying and extracting other reservoir information (e.g., permeability information); these include instantaneous Q factor, slope instantaneous frequency, slope spectral frequency, etc.

Liner et al. [98] introduced a general seismic attribute that was developed following a singularity analysis of migrated seismic data and wavelet transform decomposition. This attribute provided a dense layer model of the subsurface that contained many structural and stratigraphic details (complement coherence and impedance seismic attributes) where these kinds of geological features were associated with singularities (discontinuities in seismic impedance). In addition, this seismic attribute does not require well controls for enhancing reservoir interpretation of migrated seismic data; nevertheless, well controls give an advance petroleum reservoir characterization.

Sidney and references therein [99] provided a classification of seismic attributes based on (1) wave kinematics or dynamic categories and (2) geologic reservoir feature categories. These include:

(1) Amplitude (reflection strength, RMS amplitude, etc.), waveshape (apparent polarity and maximum peak amplitude), frequency (instantaneous frequency and average zero crossing), attenuation (amplitude slope and attenuation of sensitive bandwidth), phase (instantaneous phase and response phase), correlation (length and average), energy (reflection strength and vibration energy), and ratios (ratio of adjacent peak amplitudes).

(2) Bright and dim spots (slope of reflection strength), unconformity traps (average correlation), oil and gas bearing anomalies (instantaneous real amplitude), thin layer reservoirs (finite frequency–bandwidth energy), stratigraphic discontinuity (apparent polarity), clastic–carbonate differentiation (ratio of adjacent peak amplitudes), structural discontinuity (maximum–minimum correlation), and lithology pinch-out (cosine of instantaneous phase).

Furthermore, seismic attributes are often considered a form of "inversion", a process widely used to transform seismic reflection data into valuable and meaningful geomorphological elements and reservoir properties that can later be integrated into detailed geomorphology, reservoir geology, and simulation modeling. This inversion method integrates seismic and wellbore data from which an attribute such as acoustic impedance is derived from sonic and density logs and is subsequently used to populate their properties into the seismic cube [26,100–102].

Al-Shuhail, Al-Dossary, and Mousa [89] introduced "digital image processing" as a complement for seismic attribute analysis where advances in digital image-processing algorithms and computing technology are able to identify and delineate geological and geomorphological features from seismic reflection data. In addition, the removal of random noises and artifacts from seismic reflection data such as velocity push-down or pull-ups, seabed multiples, acquisition and processing footprints, etc., can be solved utilizing digital image-processing techniques including edge/structure-preserving smoothing algorithms [89]. This kind of technique also provides automatic interpretation based on seismic attribute analysis. In particular, these techniques performed very well on fault and channel detection using several seismic attributes such as edge detection, coherence, dip, curvature, randomness, and spectral decomposition.

4. Seismic Sedimentology

Seismic sedimentology is the use of seismic data in the study of sedimentary rocks (lithology, thickness, and fluid properties) and the depositional processes by which they were formed by revealing their sedimentary and erosional geomorphology and their relationship with preserved landforms [43,103–105]. The main tools of seismic sedimentology are ninety-degree phasing of the seismic data, seismic lithology, seismic slicing, and seismic geomorphology [43]. In addition, a display of seismic attributes on geologic time surfaces is another important tool of seismic sedimentology. However, there are strict limitations and conditions under which reservoir geometries and geomorphology can be optimally delineated on time and/or horizon slices [43,106]. This seismic sedimentology approach, which attempts to resolve the resolution of seismic reflection data, is a supplement for the existing seismic stratigraphy where the seismic response to sedimentary layers and geomorphological surfaces may act differently at low and high resolutions [43].

The ninety-degree phasing of seismic data attempts to provide the best correlation between the seismic trace, wireline lithologic logs, and stratigraphic architecture (especially in a thin-bed depositional unit) by providing a symmetrical waveform to be tied directly with the acoustic impedance profile [43,104,107,108]. The unique and symmetrical ninety-degree phasing of seismic data will eliminate the dual polarity of the thin-bed response (less amplitude distortion) that created better seismic image of thin-bed reflection termination and configuration (seismic facies), lithology, impedance profiles, and stratigraphy [43,107,108].

Seismic lithology is a reservoir geophysics technique that converts seismic traces into acoustic impedance logs (seismic inversion) to produce an acoustic impedance volume (valid impedance model) for lithologic and stratigraphic imaging at high resolutions [43,104,106]. This seismic sedimentology technique is very useful for identification and characterization of the thin-bed reservoir from 3D seismic reflection data. The thin-bed parameters might be consisting of (but not limited to) sand/shale ratio, lithofacies, shale (sand) content (as a pseudo-log), thickness of sandstone, etc. In addition, Dvorkin, Gutierrez, and Grana [21] provide the relationships between lithology (sandstone and shale), fluid, porosity, clay content, and acoustic impedance that can validate seismic lithology results, which are:

- Shale with medium-porosity gas sand.
- Shale with low-porosity gas sand.
- Gas sand and wet sand.
- Wet sand and shale.

The seismic slicing technique usually consists of time or depth, horizon, and stratal slicing types in 3D seismic reflection data that (together with seismic attribute) provide the geomorphology of geological features (Figure 2). The time or depth and horizon seismic slicing are self-explanatory, whereas the stratal slicing technique utilizes the horizontal seismic resolution of 3D seismic reflection data and spatially correlates the geological interpretation (especially at reservoir scale) in a geological timeline (Chronostratigraphy). Nevertheless, Zeng [109,110] suggests that some of parameters need to be understood to make this technique valid, which are:

- Good quality geologic-time framework should be in place.
- Depositional system should be linear with lateral changes in thickness.
- No significant angular unconformity.

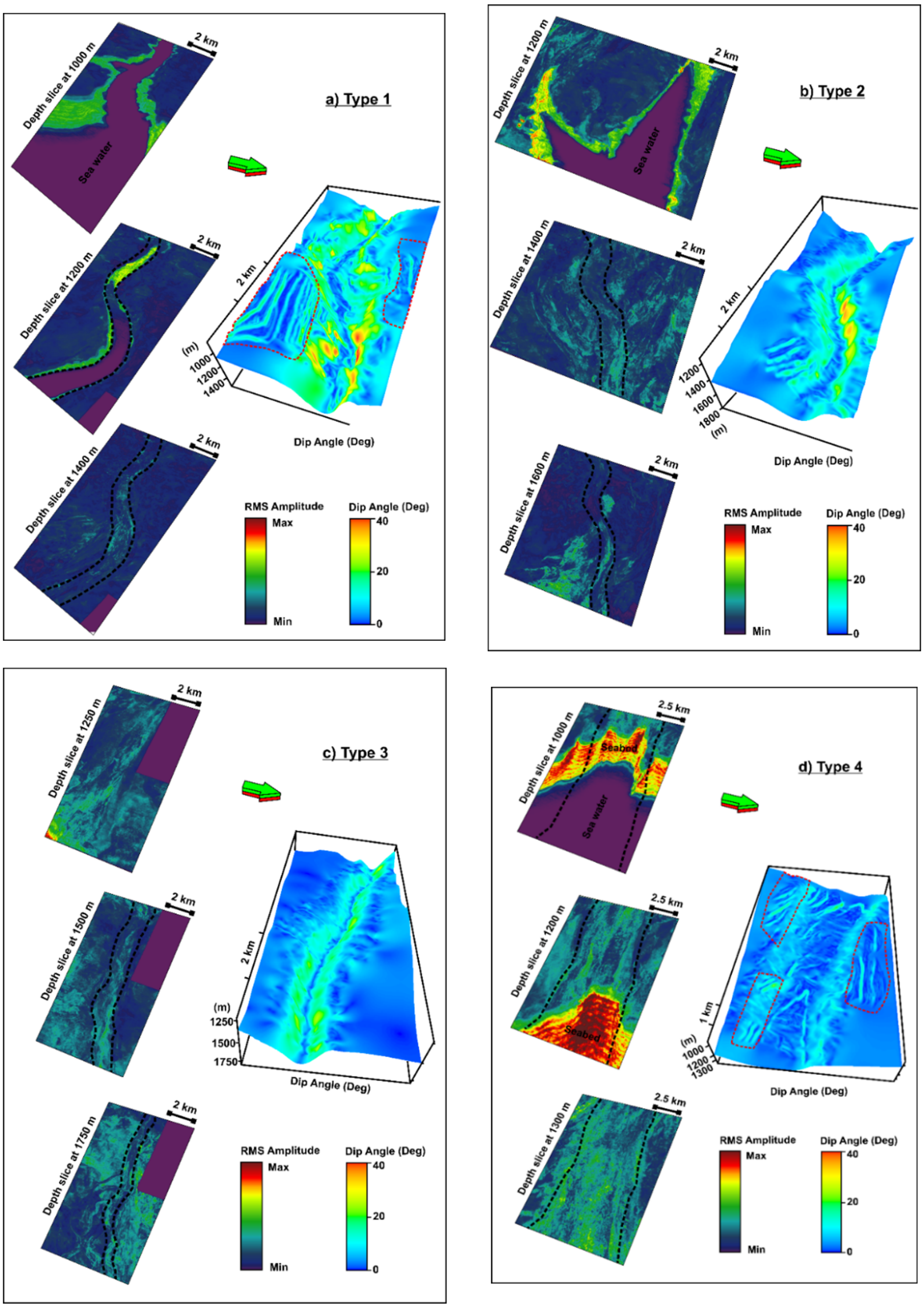

Figure 2. 3D view of dip angle (**right** images) and depth root-mean-square (RMS) amplitude slice from 3D seismic reflection data (**left** images) of (**a**) Type 1, (**b**) Type 2, (**c**) Type 3, and (**d**) Type 4 channel complexes in the Canterbury Basin, offshore of New Zealand [46]. Note that the black dashed line is the channel outline, while the red dashed line is the area of the contourite deposit.

Based on the analytical technique, seismic geomorphology involves the extraction and study of preserving subsurface landforms that utilizes plan-view images from 3D seismic reflection data by seismic slicing and seismic attribute techniques [27,29,43,111]. As part of the seismic sedimentology techniques, seismic geomorphology needs to be integrated (complementary) and evaluated with other seismic sedimentology techniques (i.e., the ninety-degree phasing of seismic data, seismic lithology, and seismic slicing) for maximum benefit on the extracting geology, geophysics, and reservoir information out of 3D seismic reflection data [24,26,43]. A study conducted by Deiana et al. [112] revealed that paleo-landscape geomorphological attributes can be extracted from seismic data acquired by MBES. By analyzing these data, the authors noticed that it was possible to identify the geometrical position of a beach rock located at 45 m of water depth (Figure 3).

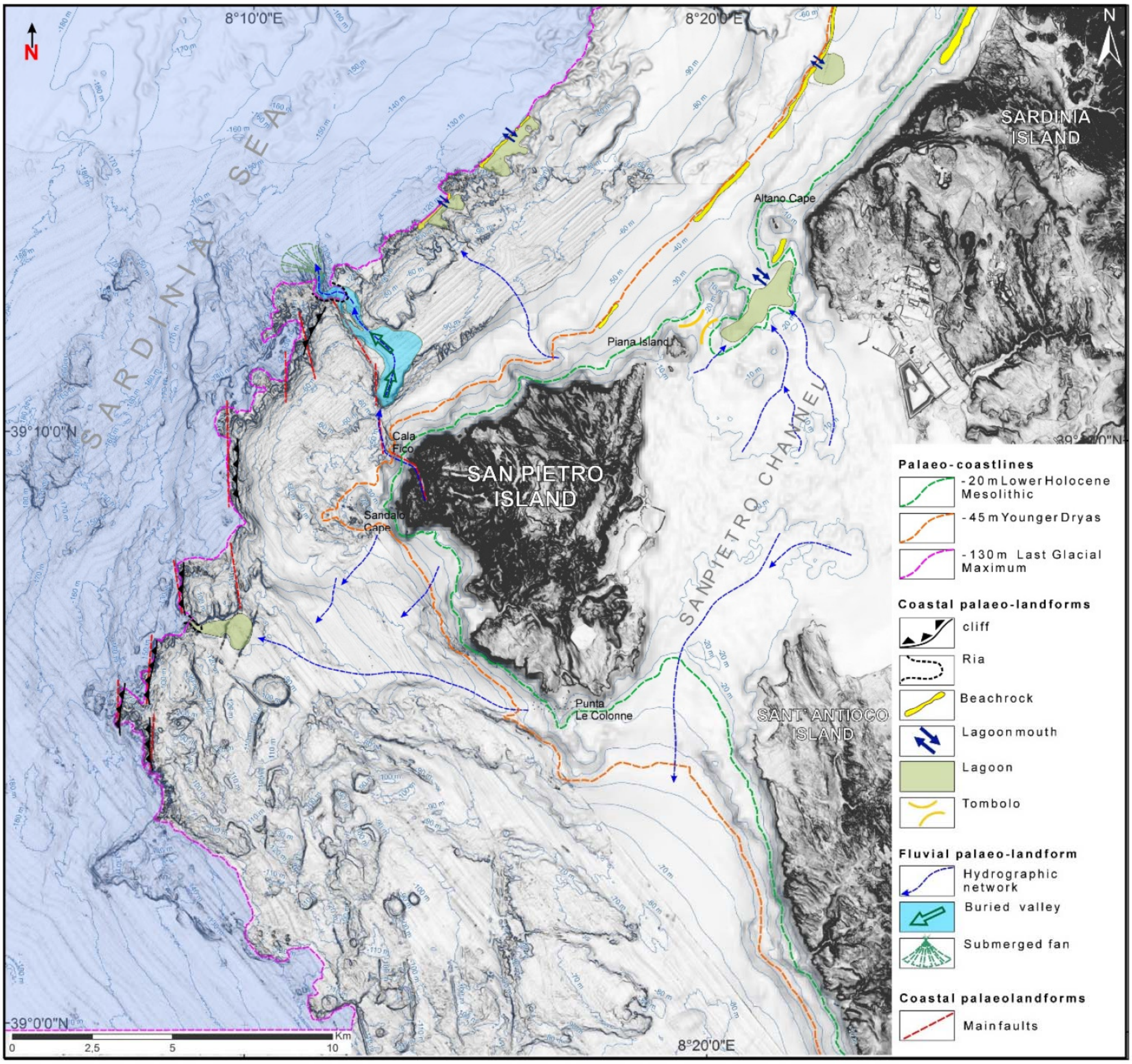

Figure 3. Geomorphological sketch of the San Pietro continental shelf. Submerged paleo-landscape from LGM (20 ka) to 9 ka [112].

5. Volume Rendering and Geobody Extractions

The earth has always been three dimensional (3D). Such dimensions can be acquired using UAV [113] and analyzed for paleo-seismic offset studies (Figure 4). Today, seismic technology is able to image a small portion of the earth using 3D seismic reflection data (primarily for energy purposes) to identify, isolate, and extract seismic anomalies (e.g., geomorphology, reservoirs, fluids, volcanic features, salt, etc.). Volume rendering and the red-green-blue (RGB) blending method as part of the seismic geomorphology technique allow users to interactively blend multiple seismic reflection volumes, identify and isolate areas of interest, and extract any relevant geologic and geomorphologic features from a 3D object called a geobody [25,26,114–121].

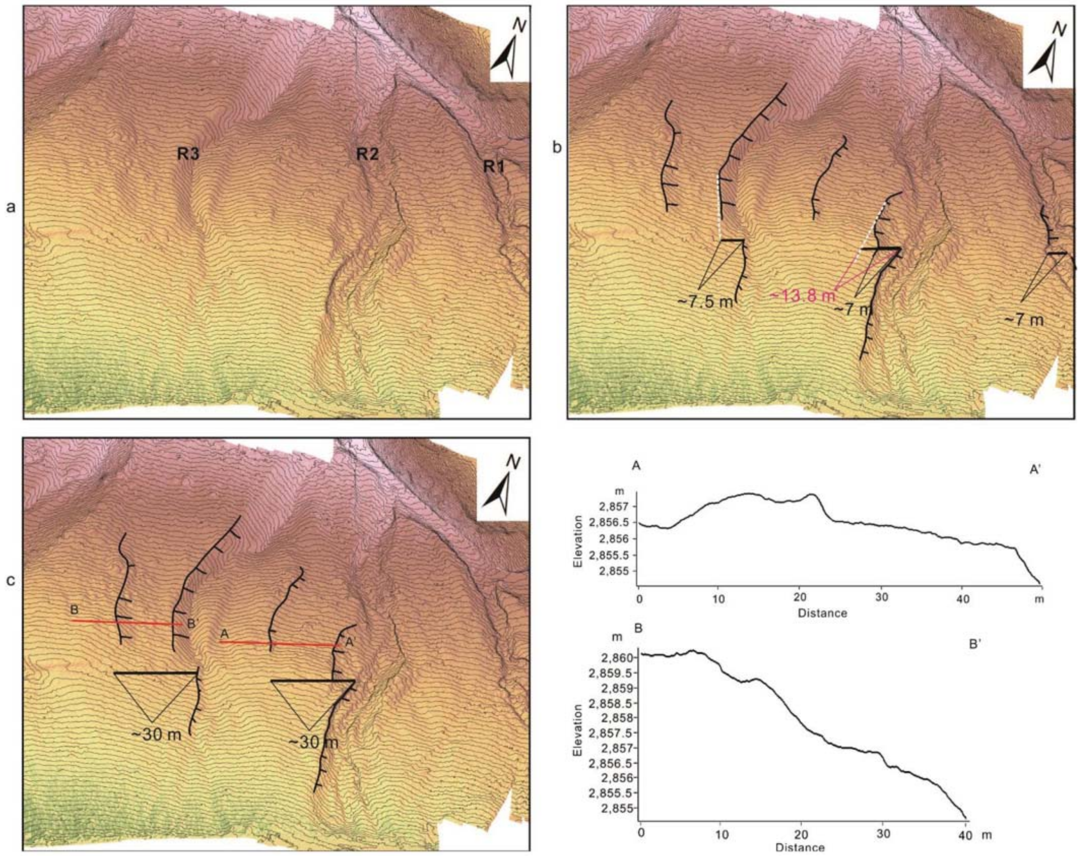

Figure 4. (**a**) Digital elevation model with contour lines (0.25 m interval) for R1, R2 and R3. (**b**) Interpretation of terrace risers and reconstruction of the ~7 m offset. (**c**) Reconstruction of the ~30 m offset [113].

In volume rendering, the volume is considered as a semi-transparent medium for each pixel of the screen, and the computation of a volume rendering integral accumulates the voxels' contribution along a virtual viewing ray [114–117,119–123]. On the other hand, the seismic volume rendering process is a display of all data within a seismic volume at the same time. By rendering a seismic volume and working with the opacity to make it partially opaque (high amplitude) and partially transparent (crossover amplitudes), it is possible to identify hidden structural, geomorphological, or depositional features.

However, at times, it is difficult to identify areas of interest with volume rendering. Therefore, the RGB method is the best option for this situation because it allows for the blending of different seismic attributes, and its opacity scale uses the primary colors (red, green, and blue), which facilitates better visualization of geological and geomorphological features [114].

Furthermore, Chopra and Marfurt [116] suggested that co-rendering seismic attributes (blending two or more seismic attributes) into a single 3D seismic volume could demonstrate the maximum value of volumetric interpretation of seismic reflection data. In addition, a false-color guidance of red-green-blue blending on co-rendering seismic attributes are as follows [116]:

- Red for lower values (less significant geological features).
- Green for intermediate values that represent geological features.
- Blue for higher values that represent more geological features.

After visualizing and isolating a 3D object through seismic volume rendering or RGB blending, the geobody can then be extracted (Figure 5). The volumetric of this geobody can then be calculated, or it can be directly sampled in a geological model as a discrete object to condition the petrophysical modelling. The resulting property can then be used in a similar way as a facies model to condition the petrophysical property models [114,121]. Therefore, the geobody provides anomalous subsurface geological features of interest to rapidly visualize the orientation, geometry, and extent in three-dimensional ways [119]. In addition, this geobody extraction also visualizes the geomorphological features with rock or physical properties from 3D seismic reflection data, and once these features are depth converted (from millisecond to meter), then such metric calculations could be possible with other supporting parameters.

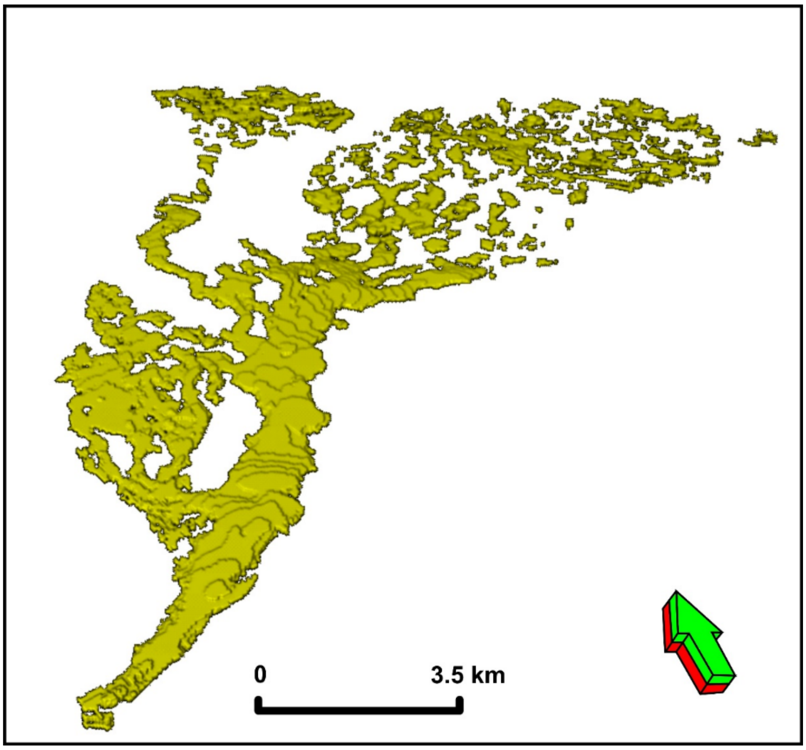

Figure 5. Geobody extraction of deep-water channel-lobe system from seismic geomorphology technique. Note that 3D red-green block is pointing toward the north direction.

Nowadays, computer technology, as well as the ability to process large-scale seismic reflection data, makes volume rendering and geobody extraction a common tool in the visualization of geology, geophysics, and reservoir features out of 3D seismic reflection data. In addition, volume rendering and geobody extraction provide more realistic subsurface features with some uncertainties based on data resolution and the workflow that was implemented in the study. Nevertheless, geological understanding of the studied area as well as integration with other subsurface datasets (e.g., wells, gravity, magnetic, etc.) are needed for obtaining more geologic interpretations (higher levels of confidence in interpretations) and low uncertainty on the subsurface model.

6. Machine Learning

Seismic reflection interpretation is usually a time-consuming process (especially with low-quality data) when the interpreter analyzes seismic data at a standard industrial workstation. This long process (potentially months) also influences the result, since the interpreter is a human that could have emotional biases when working on a project for long period of time, which might lead to less objectivity. Machine learning in seismic interpretation (seismic geomorphology, in particular) utilizes applied statistics that build computational models using various machine learning techniques such as random forests, decision trees, support-vector machines, convolutional neural networks, deep neural networks, and generative adversarial networks [124–128]. This requires input data that will be processed for training using applied statistics with computational algorithms to produce reliable outputs (Figure 6).

With today's trend toward digitalization and automation, this process will significantly reduce seismic interpretation to a very short period, possibly hours or minutes depending on the size of the seismic reflection data. Furthermore, the utilization of machine learning in seismic interpretation processes covers most of the subsurface areas, including surfaces, geomorphology and facies interpretation, e.g., [129–141], faults and fracture interpretation, e.g., [139,142–147], and geological volume-global interpretation, e.g., [128,148–150].

Machine learning in horizon seismic interpretation is an important aspect on identification geomorphology, faults, reservoir, etc. Lou, Zhang, Lin, and Cao [137] introduced that seismic horizons follow the reflector dip, thus having similar instantaneous phase values (the same horizons). Therefore, automatic horizon-interpretation algorithms need to implement the integration between the reflector dip and instantaneous phase attributes [137]. Another type of machine learning on horizon seismic interpretation is utilizing dislocated horizons (faulted, truncated, etc.) where dynamic time warping and unwrapped instantaneous phase-constraint are used to correlate horizon grids in a 3D window [133].

Geomorphological interpretation using 3D seismic reflection data is usually time-consuming, and machine learning with automation processes definitely helps to reduce the working hours of an interpreter. Infante-Paez and Marfurt [134] and La Marca and Bedle [140] presented unsupervised machine learning (self-organizing maps) on identification of deep-water and volcanic seismic facies, geomorphology, and architectural elements. Kumar and Sain [132] presented supervised learning based on an artificial neural network to automate the identification and delineation of mass-transport deposits' geomorphological surfaces and bodies out of 3D seismic reflection data (offshore).

Manual seismic facies interpretation makes the results very subjective, depending on the experience and knowledge of the interpreter. Zhang, Chen, Liu, Zhang, and Liu [131] presented automatic seismic facies interpretation utilizing deep learning, the convolutional neural network, and encoder–decoder architecture, whereas Singh, Tsvankin, and Naeini [141] utilized Bayesian inference on supervised and semi-supervised deep learning on a shallow marine prograding delta offshore of the Netherlands.

Faults and geological volume interpretations take most of the interpreter's time in manual 3D seismic interpretation. Wu, Liang, Shi, and Fomel [145] introduced "FaultSeg3D", an automatic and machine-learning tool that used an end-to-end convolutional neural network to produce an image-to-image fault segmentation. Di and AlRegib [147] presented a semi-automatic fault or fracture seismic interpretation not using the conventional-based fault interpretation on displacement, but utilizing seismic geometry analysis. Furthermore, 3D seismic interpretation is usually done using a 2D interpretation view with dependency on the human interpreter. de Groot [148] and de Groot, et al. [151] introduced "global seismic interpretation" as a seismic volume interpretation where the algorithm correlates amplitude and time lines in the pre-calculated seismic dip field.

Nevertheless, this automation and time reduction produces results that the interpreter needs to validate. We have to keep in mind that machine learning is only a tool that helps interpreters to work effectively and should not be relied on entirely.

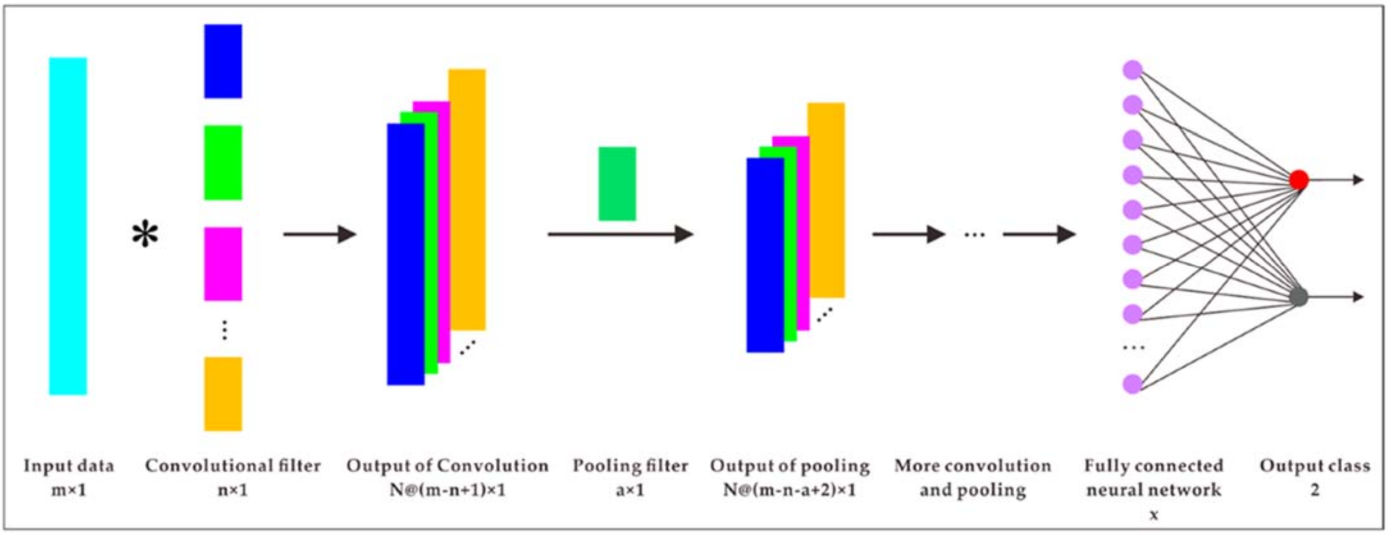

Figure 6. Convolutional Neural Network workflow [152].

7. Integrated Seismic Geomorphology with Surface Geomorphological Techniques

Seismic geomorphology, which consists of seismic attributes, seismic sedimentology, volume rendering, and geobody extraction, is a unique seismic interpretation method that produces reliable geomorphology (both surface and geobody) out of seismic reflection data. Nevertheless, the integration of surface and subsurface techniques such as digital elevation models (i.e., LIDAR, photogrammetry, and surface outcrops) and seismic geomorphology could lead to reduced data uncertainty and better geological mapping, 3D earth surface imaging (geomorphology), and reconstruction.

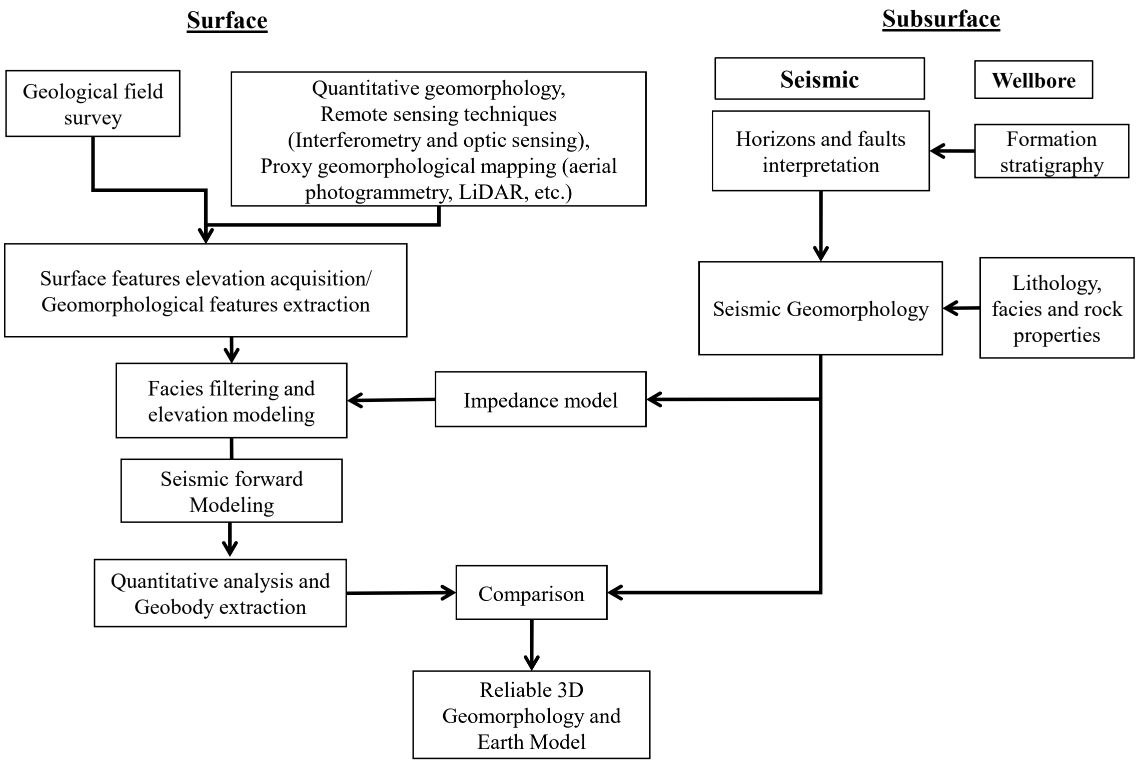

Figure 7. Proposed integrated seismic (with addition of wellbore data, if available) and surface geomorphology workflow for a reliable 3D model of the earth and its geomorphology.

This integration could be beneficial for society in various aspects, including mapping and mitigating landslides and earthquake hazards, engineering geology for building, surface-groundwater identification and utilization, city planning (land-use mapping and landscape planning), halt and reverse land degradation, characterization of sustainable energy on the land surface, better environmental management, etc. Seismic reflection data and geology itself are often difficult to correlate [4,153–160]. This is because of the different factors used to describe the two in terms of units, scales, time, and resolutions. In addition, surface data also have different factors compared to subsurface data. Therefore, we propose an integrated workflow that consists of geological fieldwork, remote sensing techniques, quantitative geomorphology, an aerial photogrammetry-based point-cloud (digital outcrop modelling), surface outcrops, LIDAR (surface data), and seismic reflection data (i.e., seismic geomorphology for subsurface data) to bridge the gap between seismic reflection data (geology) and surface outcrops to produce a reliable 3D model of the earth and its geomorphology (Figure 7).

Subsurface data mainly consists of seismic and wellbore data (and other data, e.g., gravity, magnetic, ground-penetrating radar, etc). The basic interpretations from this subsurface dataset are horizon (utilizing formation stratigraphy from wellbore) and fault interpretations that lead to seismic geomorphology, lithology, facies, and rock properties (Figure 7). The surface data is a combination of geological field work data (lithology, faults, geomorphology, etc.) and surface geomorphological techniques, e.g., drone photogrammetry (digital outcrop model), LIDAR, etc. The basic interpretation from this surface geomorphology technique is surface geomorphological feature identification and characterization. This feature usually extends and relates to the subsurface, and the seismic geomorphology technique is needed to image the subsurface and correlate this surface feature with its subsurface counterpart. Since there is a difference domain between two datasets (depth, amplitude values, etc.), an impedance model (consisting of mainly density and velocity data) with facies and a rock model consisting of rock properties (e.g., density, porosity, permeability, etc.) will be a bridge between seismic geomorphology and surface geomorphology (seismic forward modelling). The final surface geomorphology product is a geomorphology volume that could render and extract specific geomorphology feature (Geobody). Furthermore, the seismic geomorphology and geobody need to be compared to produce a reliable 3D model of the earth and its geomorphology. In addition, results from all the techniques will depend on the quality of the data that has limitations as functions of vertical and horizontal data resolutions. Therefore, the results and technological preference are very dependent on data resolution. Nevertheless, all techniques should be implemented in order to reduce the uncertainty coming from the data.

In addition, this kind of integration is also beneficial for reducing the uncertainty that is produced by surface and subsurface data, whereas more accuracy is always needed utilizing updated technology for surface and subsurface data. Finally, our integrated workflow that helps for better geomorphological mapping as well as 3D earth surface imaging and reconstruction could be applicable with available and similar datasets worldwide.

8. Discussions and Results Overview

Several seismic and surface geomorphology techniques exist for delineating, identifying, and extracting the geomorphology features from both seismic reflection and surface geomorphology data (Table 2).

Table 2. Seismic geomorphology technical analysis.

Techniques	Geomorphological Analysis and Frequency	Scale and Resolution	Results	Ratios (In Time) and References
Seismic attribute	Most cases, often used	Vertical (20–30 m) & horizontal (10–20 m)	Good (Depends on data quality)	1980s—now, see chapter 3
Seismic sedimentology	In special cases (e.g., thin bedded)	Vertical (2–10 m) & horizontal (10–20 m)	Good for thin bedded	2010s—now, see chapter 4
Volume rendering and geobody extraction	In special cases (e.g., (3D seismic reflection data)	Vertical (20–30 m) & horizontal (10–20 m)	Good (Depends on data quality)	2000s—now, see chapter 5
Machine learning	Becoming often (Last decade)	Vertical (20–30 m) & horizontal (10–20 m)	Good (Needs human validation)	2010s—now, see chapter 6
Integrated seismic and surface geomorphology	Not often, lack of reference	Vertical (2–10 m) & horizontal (10–20 m)	Better (Reducing result uncertainty)	Proposed (This study)

The seismic attribute technique (including geometrical attribute: seismic facies) is widely used as the first approach of quantitatively identifying geological and geomorphological features from seismic reflection data. Therefore, this kind of seismic geomorphology technique is often used in industry and academia since its introduction back in the 1980s. The results offered by this technique really depend on the quality of seismic reflection data together with human knowledge and experience (Table 2). The seismic sedimentology technique is a relatively new technique that deals with thin-bedded geology and geomorphology (Table 2), thus, it needs the human knowledge and experience to provide a good result. Thin-bedded features could be in a range of 2 to 10 m thick with horizontal resolution of the conventional seismic reflection data. This kind of technique is usually ignored when the seismic attributes technique could solve the problem of imaging geomorphological features from seismic reflection data. Furthermore, volume rendering and geobody extraction depend on the availability of 3D seismic reflection data (Table 2). Application of this technique will also be dependent on the objective of the project; it is mainly used for volume calculation of the geological and geomorphological features. The results offered would depend on the quality of the seismic reflection data (Table 2). The machine learning technique could also be applied on the seismic geomorphology technique to speed up the interpretation processes. Nowadays, this kind of technique is often used, but the results offered always need to be validated by human experience and knowledge (Table 2). The surface geomorphology techniques combining a large number of emerging space and proxy-remote sensing technologies are presented as the best techniques used for local, regional, and continental geomorphological studies (Table 3). Such techniques improve the ability to acquire the surface feature of elevation and to extract geomorphological features. In addition, the proliferation of a large number of GEE and GIS software allow for facies filtering and elevation modeling in quantitative analysis and geobody extraction studies, and eventually allowing the development of a reliable 3D geomorphological earth surface model.

Table 3. Surface geomorphology technical analysis.

Techniques	Geomorphological Analysis	Scale of Studied Area	Results	References
Remote sensing techniques	Surface Depressions Surface processes Surface deformation	Local, Reginal, Continental	Information on the location, distance, and volume	Melis et al. 2021 [59] Muzirafuti et al. 2020 [52] Borzì et al. 2021 [64] Bianco et al. 2021 [65] Randazzo et al. 2020 [67] Cigna et al. 2021 [68] Mantovani et al. 2016 [69] Jiang et al. 2021 [71] Crosetto et al. 2020 [72] van Natijne et al. 2022 [76]
Proxy geomorphological mapping (aerial photogrammetry, LiDAR.)	Surface and marine processes Surface and marine features	Regional local	Information on the location, distance, and volume, 3D models	Randazzo et al.2020 [67] Anders et al. 2021 [62] Bonasera et al. 2022 [63] Muzirafuti et al. 2021 [73] Deiana et al. 2021 [112] Gao et al. 2017 [113]
Geological field survey	Surface and marine processes	Local	Information on the location, distance, and volume	Bonasera et al. 2022 [63] Taufani et al. 2021 [155]
Quantitative geomorphology	Marine sedimentary features	Local	Information on the location, distance, and volume	Distefano et al. 2021 [51] Muzirafuti et al. 2021 [73]

Finally, the integration of the seismic and surface geomorphology workflow is proposed to give better results for reconstructing land and marine features (Figure 7 and Table 1). The data quality together with human knowledge and experience will influence the results, but this integrated workflow will reduce the uncertainty about the results since it combines several seismic and surface geomorphology techniques that can complement each other.

9. Conclusions

We presented a review of seismic and surface geomorphology techniques for imaging and reconstructing land and marine geomorphology features, and we have revealed that:

- Seismic geomorphology is a subsurface (including near surface) study that extracts geomorphology features out of 3D seismic reflection data.
- Active proxy of surface geomorphology techniques and remote sensing techniques have huge potential in vertical and horizontal deformation monitoring.
- The reconstruction of high-resolution images of land and marine surface features by surface and subsurface geomorphology techniques is reliable through several techniques, including seismic sedimentology, volume rendering, geobody extraction, quantitative geomorphology approaches, and mapping.
- The integration of surface and subsurface techniques provides more realistic and suitable 3D models of the earth and its geomorphology. In addition, it enhances the interpretation of sedimentary processes, geomorphology, the earth's surface, the paleoenvironment, economical prospective, natural hazards, etc. Therefore, we propose a workflow that integrates surface and subsurface techniques to provide realistic and acceptable earth models.

Author Contributions: Conceptualization, A.A.-S., A.M., and D.H.; methodology, D.H. and A.M.; software, D.H. and A.M.; validation, A.A.-S., D.H., A.M., G.R., and S.L.; formal analysis, D.H. and A.M.; investigation, A.A.-S., D.H., A.M., G.R., and S.L.; resources, A.A.-S., A.M.; data curation, D.H. and A.M.; writing—original draft preparation, A.A.-S., D.H., and A.M.; writing—review and editing, A.A.-S., D.H., A.M., G.R., and S.L.; visualization, D.H., A.M., G.R., and S.L.; supervision, A.A.-S., G.R. and A.M.; project ad-ministration, A.A.-S. and G.R.; funding acquisition, A.A.-S. and A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by King Fahd University of Petroleum & Minerals through College of Petroleum Engineering & Geosciences Startup grant number SF18060 and the APC was funded also by the same grant. The research was conducted in the framework of REACT EU-National opera-tional program "PON Research and Innovation" 2014-2020 on innovation and green issues (DM 1062/2021) granted in December 2021 for quantitative geomorphology from images project.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank Department of Geosciences, College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum and Minerals (KFUPM), Kingdom of Saudi Arabia for supporting this work. This publication is based upon work supported by King Fahd University of Petroleum & Minerals and the author(s) at KFUPM acknowledge the support. This paper is part of Special Issue: "Geomorphology in the Digital Era" on the MDPI Applied Science section: "Earth Sciences and Geography".

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chopra, S.; Marfurt, K.J. Evolution of seismic interpretation during the last three decades. *Lead. Edge* **2012**, *31*, 654–676. [CrossRef]
2. Doust, H. The exploration play: What do we mean by it? *AAPG Bull.* **2010**, *94*, 1657–1672. [CrossRef]
3. Weimer, P.; Slatt, R.M.; Bouroullec, R.; Fillon, R.; Pettingill, H.; Pranter, M.; Tari, G. Reservoir Quality of Deepwater Deposits. In *Introduction to the Petroleum Geology of Deepwater Setting*; American Association of Petroleum Geologists: Tulsa, Ok, USA, 2006; Volume 57.
4. Harishidayat, D.; Taufani, L.; Fardiansyah, I.; Wibowo, A. Integrated Digital Outcrop Model (DOM) and Seismic Forward Modeling: Application to Enhance Subsurface Interpretation in Deltaic System of Kutai Basin, East Kalimantan. *Indones. Pet. Assoc.* **2017**. [CrossRef]
5. Grammer, G.M.; Harris, P.M.M.; Eberli, G.P. *Integration of Outcrop and Modern Analogs in Reservoir Modeling*; American Association of Petroleum Geologists: Tulsa, Ok, USA, 2004.
6. Sullivan, M.D.; Foreman, J.L.; Jennette, D.C.; Stern, D.; Jensen, G.N.; Goulding, F.J.; Grammer, G.M.; Harris, P.M.M.; Eberli, G.P. An Integrated Approach to Characterization and Modeling of Deep-water Reservoirs, Diana Field, Western Gulf of Mexico. In *Integration of Outcrop and Modern Analogs in Reservoir Modeling*; American Association of Petroleum Geologists: Tulsa, Ok, USA, 2004.
7. Gluyas, J.; Swarbrick, R. *Petroleum Geoscience*; John Wiley & Sons: Hoboken, NJ, USA, 2013.
8. Harishidayat, D. *Architecture, Morphometry and Development of Subaqueous Sediment Conduits*; Norwegian University of Science and Technology: Trondheim, Norway, 2021.
9. Kemper, M.; Abel, M.; De Ros, L.; Hansford, J. Integration of Lithological Data for Advanced Seismic Inversion. In *Third EAGE/SBGf Workshop 2016*; European Association of Geoscientists & Engineers: Amsterdam, The Netherlands, 2016.
10. Sams, M.; Millar, I.; Satriawan, W.; Saussus, D.; Bhattacharyya, S. Integration of geology and geophysics through geostatistical inversion: A case study. *First Break* **2011**, *29*, 47–56. [CrossRef]
11. Brown, A.R. *Interpretation of Three-Dimensional Seismic Data*, 7th ed.; Society of Exploration Geophysicists: Houston, TX, USA; The American Association of Petroleum Geologists: Tulsa, Ok, USA, 2011.
12. Cartwright, J.; Huuse, M. 3D seismic technology: The geological 'Hubble'. *Basin Res.* **2005**, *17*, 1–20. [CrossRef]
13. Davies, R.J.; Posamentier, H.W. Geologic processes in sedimentary basins inferred from three-dimensional seismic imaging. *GSA Today* **2005**, *15*, 4. [CrossRef]
14. Herron, D.A. *First Steps in Seismic Interpretation*; Society of Exploration Geophysicists: Houston, TX, USA, 2011.
15. Posamentier, H.W.; Paumard, V.; Lang, S.C. Principles of seismic stratigraphy and seismic geomorphology I: Extracting geologic insights from seismic data. *Earth-Sci. Rev.* **2022**, *228*, 103963. [CrossRef]
16. Avseth, P.; Mukerji, T.; Mavko, G. *Quantitative Seismic Interpretation: Applying Rock Physics Tools to Reduce Interpretation Risk*; Cambridge University Press: Cambridge, UK, 2010.
17. Cox, D.R.; Newton, A.M.; Huuse, M. An introduction to seismic reflection data: Acquisition, processing and interpretation. In *Regional Geology and Tectonics*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 571–603.
18. Badley, M. *Advanced Practical Seismic Interpretation*; IHRDC Press: Boston, MA, USA, 1992.
19. Badley, M.E. *Practical Seismic Interpretation*; IHRDC Press: Boston, MA, USA, 1985.
20. Davies, R.J.; Posamentier, H.W.; Wood, L.J.; Cartwright, J.A. *Seismic Geomorphology: Applications to Hydrocarbon Exploration and Production*; GSL Special Publications: London, UK, 2006; p. 276.
21. Dvorkin, J.; Gutierrez, M.A.; Grana, D. *Seismic Reflections of Rock Properties*; Cambridge University Press: Cambridge, UK, 2014.
22. Schultz, P. *The Seismic Velocity Model as an Interpretation Asset*; Society of Exploration Geophysicists: Houston, TX, USA, 1998.
23. Sheriff, R.E.; Geldart, L.P. *Exploration Seismology*; Cambridge University Press: Cambridge, UK, 1995.

24. Omosanya, K.O.; Harishidayat, D. Seismic geomorphology of Cenozoic slope deposits and deltaic clinoforms in the Great South Basin (GSB) offshore New Zealand. *Geo-Mar. Lett.* **2019**, *39*, 77–99. [CrossRef]
25. Harishidayat, D.; Johansen, S.E.; Batchelor, C.; Omosanya, K.O.; Ottaviani, L. Pliocene–Pleistocene glacimarine shelf to slope processes in the south-western Barents Sea. *Basin Res.* **2021**, *33*, 1315–1336. [CrossRef]
26. Harishidayat, D.; Omosanya, K.O.; Johansen, S.E. 3D seismic interpretation of the depositional morphology of the Middle to Late Triassic fluvial system in Eastern Hammerfest Basin, Barents Sea. *Mar. Pet. Geol.* **2015**, *68*, 470–479. [CrossRef]
27. Posamentier, H.W. Seismic Geomorphology: Imaging Elements of Depositional Systems from Shelf to Deep Basin Using 3D Seismic Data: Implications for Exploration and Development. *Geol. Soc. Lond. Mem.* **2004**, *29*, 11–24. [CrossRef]
28. Posamentier, H.W. Application of 3D seismic visualization techniques for seismic stratigraphy, seismic geomorphology and depositional systems analysis: Examples from fluvial to deep-marine depositional environments. *Geol. Soc. Lond. Pet. Geol. Conf. Ser.* **2005**, *6*, 1565–1576. [CrossRef]
29. Posamentier, H.W.; Davies, R.J.; Cartwright, J.A.; Wood, L. Seismic geomorphology–An overview. *Geol. Soc. Lond. Spec. Publ.* **2007**, *277*, 1–14. [CrossRef]
30. Harishidayat, D.; Farouk, S.; Abioui, M.; Aziz, O.A. Subsurface Fluid Flow Feature as Hydrocarbon Indicator in the Alamein Basin, Onshore Egypt; Seismic Attribute Perspective. *Energies* **2022**, *15*, 3048. [CrossRef]
31. Harishidayat, D.; Emmel, B.U.; De Jager, G.; Johansen, S.E. Assessment of continental margin clinoform systems in the Sørvestsnaget Basin, western Barents Sea: From clinoform parameters towards paleo-water depth. *Mar. Geophys. Res.* **2022**, *43*, 22. [CrossRef]
32. Alfaro, E.; Holz, M. Seismic geomorphological analysis of deepwater gravity-driven deposits on a slope system of the southern Colombian Caribbean margin. *Mar. Pet. Geol.* **2014**, *57*, 294–311. [CrossRef]
33. Bourget, J.; Ainsworth, R.B.; Thompson, S. Seismic stratigraphy and geomorphology of a tide or wave dominated shelf-edge delta (NW Australia): Process-based classification from 3D seismic attributes and implications for the prediction of deep-water sands. *Mar. Pet. Geol.* **2014**, *57*, 359–384. [CrossRef]
34. Burton, D.; Wood, L.J. Seismic geomorphology and tectonostratigraphic fill of half grabens, West Natuna Basin, Indonesia. *AAPG Bull.* **2010**, *94*, 1695–1712. [CrossRef]
35. Dalla Valle, G.; Gamberi, F.; Rocchini, P.; Minisini, D.; Errera, A.; Baglioni, L.; Trincardi, F. 3D seismic geomorphology of mass transport complexes in a foredeep basin: Examples from the Pleistocene of the Central Adriatic Basin (Mediterranean Sea). *Sediment. Geol.* **2013**, *294*, 127–141. [CrossRef]
36. Gee, M.J.R.; Gawthorpe, R.L.; Bakke, K.; Friedmann, S.J. Seismic Geomorphology and Evolution of Submarine Channels from the Angolan Continental Margin. *J. Sediment. Res.* **2007**, *77*, 433–446. [CrossRef]
37. Hadler-Jacobsen, F.; Gardner, M.H.; Borer, J.M. Seismic stratigraphic and geomorphic analysis of deep-marine deposition along the West African continental margin. *Geol. Soc. Lond. Spec. Publ.* **2007**, *277*, 47–84. [CrossRef]
38. Infante-Paez, L.; Marfurt, K.J. Seismic expression and geomorphology of igneous bodies: A Taranaki Basin, New Zealand, case study. *Interpretation* **2017**, *5*, SK121–SK140. [CrossRef]
39. Qin, Y.; Alves, T.M.; Constantine, J.; Gamboa, D. Quantitative seismic geomorphology of a submarine channel system in SE Brazil (Espírito Santo Basin): Scale comparison with other submarine channel systems. *Mar. Pet. Geol.* **2016**, *78*, 455–473. [CrossRef]
40. Rankey, E.C. Seismic architecture and seismic geomorphology of heterozoan carbonates: Eocene-Oligocene, Browse Basin, Northwest Shelf, Australia. *Mar. Pet. Geol.* **2017**, *82*, 424–443. [CrossRef]
41. Scarselli, N.; McClay, K.; Elders, C. Seismic geomorphology of cretaceous megaslides offshore Namibia (Orange Basin): Insights into segmentation and degradation of gravity-driven linked systems. *Mar. Pet. Geol.* **2016**, *75*, 151–180. [CrossRef]
42. Bischoff, A.; Planke, S.; Holford, S.; Nicol, A. Seismic geomorphology, architecture and stratigraphy of volcanoes buried in sedimentary basins. In *Updates in Volcanology-Transdisciplinary Nature of Volcano Science*; IntechOpen: London, UK, 2021.
43. Zeng, H. What is seismic sedimentology? A tutorial. *Interpretation* **2018**, *6*, SD1–SD12. [CrossRef]
44. Omosanya, K.O.; Harishidayat, D.; Marheni, L.; Johansen, S.E.; Felix, M.; Abrahamson, P. Recurrent mass-wasting in the Sørvestsnaget Basin Southwestern Barents Sea: A test of multiple hypotheses. *Mar. Geol.* **2016**, *376*, 175–193. [CrossRef]
45. Harishidayat, D.; Omosanya, K.O.; Johansen, S.E.; Eruteya, O.E.; Niyazi, Y. Morphometric analysis of sediment conduits on a bathymetric high: Implications for palaeoenvironment and hydrocarbon prospectivity. *Basin Res.* **2018**, *30*, 1015–1041. [CrossRef]
46. Harishidayat, D.; Raja, W.R. Quantitative Seismic Geomorphology of Four Different Types of the Continental Slope Channel Complexes in the Canterbury Basin, New Zealand. *Appl. Sci.* **2022**, *12*, 4386. [CrossRef]
47. Shumaker, L.E.; Jobe, Z.R.; Johnstone, S.A.; Pettinga, L.A.; Cai, D.; Moody, J.D. Controls on submarine channel-modifying processes identified through morphometric scaling relationships. *Geosphere* **2018**, *14*, 2171–2187. [CrossRef]
48. Kristensen, T.B.; Huuse, M.; Piotrowski, J.A.; Clausen, O.R. A morphometric analysis of tunnel valleys in the eastern North Sea based on 3D seismic data. *J. Quat. Sci.* **2007**, *22*, 801–815. [CrossRef]
49. Niyazi, Y.; Eruteya, O.E.; Omosanya, K.O.; Harishidayat, D.; Johansen, S.E.; Waldmann, N. Seismic geomorphology of submarine channel-belt complexes in the Pliocene of the Levant Basin, offshore central Israel. *Mar. Geol.* **2018**, *403*, 123–138. [CrossRef]
50. Wood, L.J. Quantitative Seismic Geomorphology of Pliocene and Miocene Fluvial Systems in the Northern Gulf of Mexico, U.S.A. *J. Sediment. Res.* **2007**, *77*, 713–730. [CrossRef]
51. Distefano, S.; Gamberi, F.; Borzì, L.; Di Stefano, A. Quaternary coastal landscape evolution and sea-level rise: An example from south-east sicily. *Geosciences* **2021**, *11*, 506. [CrossRef]

52. Muzirafuti, A.; Barreca, G.; Crupi, A.; Faina, G.; Paltrinieri, D.; Lanza, S.; Randazzo, G. The contribution of multispectral satellite image to shallowwater bathymetry mapping on the Coast of Misano Adriatico, Italy. *J. Mar. Sci. Eng.* **2020**, *8*, 126. [CrossRef]
53. Muzirafuti, A.; Crupi, A.; Lanza, S.; Barreca, G.; Randazzo, G. Shallow water bathymetry by satellite image: A case study on the coast of San Vito Lo Capo Peninsula, Northwestern Sicily, Italy. In Proceedings of the 2019 IMEKO TC19 International Workshop on Metrology for the Sea: Learning to Measure Sea Health Parameters, MetroSea 2019, Genoa, Italy, 3–5 October 2019; pp. 129–134.
54. Harvey, A. *Introducing Geomorphology: A Guide to Landforms and Processes*; Dunedin Academic Press Ltd.: Edinburgh, UK, 2012.
55. Huggett, R.J. *Fundamentals of Geomorphology*; Routledge: London, UK, 2016.
56. Holden, J. *An Introduction to Physical Geography and the Environment*; Pearson Education: London, UK, 2017.
57. Bierman, P.R.; Montgomery, D.R. *Key Concepts in Geomorphology*; W. H. Freeman and Company Publisher: New York, NY, USA, 2020.
58. Pieri, D. Geomorphology. In *Encyclopedia of Remote Sensing*; Njoku, E.G., Ed.; Springer: New York, NY, USA, 2014; pp. 237–241.
59. Melis, M.T.; Pisani, L.; De Waele, J. On the Use of Tri-Stereo Pleiades Images for the Morphometric Measurement of Dolines in the Basaltic Plateau of Azrou (Middle Atlas, Morocco). *Remote Sens.* **2021**, *13*, 4087. [CrossRef]
60. Muzirafuti, A.; Boualoul, M.; Barreca, G.; Allaoui, A.; Bouikbane, H.; Lanza, S.; Crupi, A.; Randazzo, G. Fusion of Remote Sensing and Applied Geophysics for Sinkholes Identification in Tabular Middle Atlas of Morocco (the Causse of El Hajeb): Impact on the Protection of Water Resource. *Resources* **2020**, *9*, 51. [CrossRef]
61. Randazzo, G.; Italiano, F.; Micallef, A.; Tomasello, A.; Cassetti, F.P.; Zammit, A.; D'Amico, S.; Saliba, O.; Cascio, M.; Cavallaro, F.; et al. WebGIS Implementation for Dynamic Mapping and Visualization of Coastal Geospatial Data: A Case Study of BESS Project. *Appl. Sci.* **2021**, *11*, 8233. [CrossRef]
62. Anders, K.; Winiwarter, L.; Mara, H.; Lindenbergh, R.; Vos, S.E.; Höfle, B. Fully automatic spatiotemporal segmentation of 3D LiDAR time series for the extraction of natural surface changes. *ISPRS J. Photogramm. Remote Sens.* **2021**, *173*, 297–308. [CrossRef]
63. Bonasera, M.; Cerrone, C.; Caso, F.; Lanza, S.; Fubelli, G.; Randazzo, G. Geomorphological and Structural Assessment of the Coastal Area of Capo Faro Promontory, NE Salina (Aeolian Islands, Italy). *Land* **2022**, *11*, 1106. [CrossRef]
64. Borzì, L.; Anfuso, G.; Manno, G.; Distefano, S.; Urso, S.; Chiarella, D.; Di Stefano, A. Shoreline evolution and environmental changes at the nw area of the gulf of gela (Sicily, Italy). *Land* **2021**, *10*, 1034. [CrossRef]
65. Bianco, F.; Conti, P.; García-Ayllon, S.; Pranzini, E. An integrated approach to analyze sedimentary stock and coastal erosion in vulnerable areas: Resilience assessment of san vicenzo's coast (Italy). *Water* **2020**, *12*, 805. [CrossRef]
66. Cinelli, I.; Anfuso, G.; Bartoletti, E.; Rossi, L.; Pranzini, E. The making of a gravel beach (Cavo, Elba Island, Italy). *J. Mar. Sci. Eng.* **2021**, *9*, 1148. [CrossRef]
67. Randazzo, G.; Barreca, G.; Cascio, M.; Crupi, A.; Fontana, M.; Gregorio, F.; Lanza, S.; Muzirafuti, A. Analysis of very high spatial resolution images for automatic shoreline extraction and satellite-derived bathymetry mapping. *Geosciences* **2020**, *10*, 172. [CrossRef]
68. Cigna, F.; Tapete, D. Sentinel-1 Big Data Processing with P-SBAS InSAR in the Geohazards Exploitation Platform: An Experiment on Coastal Land Subsidence and Landslides in Italy. *Remote Sens.* **2021**, *13*, 885. [CrossRef]
69. Mantovani, M.; Devoto, S.; Piacentini, D.; Prampolini, M.; Soldati, M.; Pasuto, A. Advanced SAR interferometric analysis to support geomorphological interpretation of slow-moving coastal landslides (Malta, Mediterranean Sea). *Remote Sens.* **2016**, *8*, 443. [CrossRef]
70. Cigna, F.; Tapete, D. Urban growth and land subsidence: Multi-decadal investigation using human settlement data and satellite InSAR in Morelia, Mexico. *Sci. Total Environ.* **2022**, *811*, 152211. [CrossRef]
71. Jiang, H.; Balz, T.; Cigna, F.; Tapete, D. Land subsidence in wuhan revealed using a non-linear PSInSAR approach with long time series of COSMO-SkyMed SAR data. *Remote Sens.* **2021**, *13*, 1256. [CrossRef]
72. Crosetto, M.; Solari, L.; Mróz, M.; Balasis-Levinsen, J.; Casagli, N.; Frei, M.; Oyen, A.; Moldestad, D.A.; Bateson, L.; Guerrieri, L.; et al. The evolution of wide-area DInSAR: From regional and national services to the European ground motion service. *Remote Sens.* **2020**, *12*, 2043. [CrossRef]
73. Muzirafuti, A.; Randazzo, G.; Maria, C.; Lanza, S. *UAV Photogrammetry-Based Mapping of the Pocket Beaches of Isola Bella Bay, Taormina (Eastern Sicily)*; The Institute of Electrical and Electronics Engineers (IEEE): Calabria, Italy, 2021.
74. Makama, A.; Kuladinithi, K.; Timm-Giel, A. Wireless Geophone Networks for Land Seismic Data Acquisition: A Survey, Tutorial and Performance Evaluation. *Sensors* **2021**, *21*, 5171. [CrossRef] [PubMed]
75. Canty, M.J.; Nielsen, A.A.; Conradsen, K.; Skriver, H. Statistical Analysis of Changes in Sentinel-1 Time Series on the Google Earth Engine. *Remote Sens.* **2020**, *12*, 46. [CrossRef]
76. Van Natijne, A.L.; Bogaard, T.A.; van Leijen, F.J.; Hanssen, R.F.; Lindenbergh, R.C. World-wide InSAR sensitivity index for landslide deformation tracking. *Int. J. Appl. Earth Obs. Geoinf.* **2022**, *111*, 102829. [CrossRef]
77. Garcia, G.P.B.; Grohmann, C.H. DEM-based geomorphological mapping and landforms characterization of a tropical karst environment in southeastern Brazil. *J. South Am. Earth Sci.* **2019**, *93*, 14–22. [CrossRef]
78. Magliulo, P.; Valente, A. GIS-Based geomorphological map of the Calore River floodplain near Benevento (Southern Italy) overflooded by the 15th october 2015 event. *Water* **2020**, *12*, 148. [CrossRef]
79. Conforti, M.; Mercuri, M.; Borrelli, L. Morphological changes detection of a large earthflow using archived images, lidar-derived dtm, and uav-based remote sensing. *Remote Sens.* **2021**, *13*, 120. [CrossRef]

80. Brunier, G.; Fleury, J.; Anthony, E.J.; Pothin, V.; Vella, C.; Dussouillez, P.; Gardel, A.; Michaud, E. Structure-From-Motion photogrammetry for highresolution coastal and fluvial geomorphic surveys. *Geomorphol. Relief Processus Environ.* **2016**, *22*, 147–161. [CrossRef]
81. Mohamed Shaffril, H.A.; Samsuddin, S.F.; Abu Samah, A. The ABC of systematic literature review: The basic methodological guidance for beginners. *Qual. Quant.* **2021**, *55*, 1319–1346. [CrossRef]
82. Munn, Z.; Peters, M.D.J.; Stern, C.; Tufanaru, C.; McArthur, A.; Aromataris, E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med. Res. Methodol.* **2018**, *18*, 143. [CrossRef] [PubMed]
83. Snyder, H. Literature review as a research methodology: An overview and guidelines. *J. Bus. Res.* **2019**, *104*, 333–339. [CrossRef]
84. Xiao, Y.; Watson, M. Guidance on conducting a systematic literature review. *J. Plan. Educ. Res.* **2019**, *39*, 93–112. [CrossRef]
85. Cook, K.L.; Dietze, M. Seismic Advances in Process Geomorphology. *Annu. Rev. Earth Planet. Sci.* **2022**, *50*, 183–204. [CrossRef]
86. Schrott, L.; Sass, O. Application of field geophysics in geomorphology: Advances and limitations exemplified by case studies. *Geomorphology* **2008**, *93*, 55–73. [CrossRef]
87. Kruse, S. 3.5 Near-Surface Geophysics in Geomorphology. In *Treatise on Geomorphology*; Shroder, J.F., Ed.; Academic Press: San Diego, CA, USA, 2013; pp. 103–129.
88. Chopra, S.; Marfurt, K. Curvature attribute applications to 3D surface seismic data. *Lead. Edge* **2007**, *26*, 404–414. [CrossRef]
89. Al-Shuhail, A.A.; Al-Dossary, S.A.; Mousa, W.A. *Seismic Data Interpretation Using Digital Image Processing*; John Wiley & Sons: Hoboken, NJ, USA, 2017.
90. Brown, A.R. 8a. Horizon and Formation Attributes. In *Interpretation of Three-Dimensional Seismic Data*; Society of Exploration Geophysicists: Houston, TX, USA; American Association of Petroleum Geologists: Tulsa, Ok, USA, 2011; pp. 247–282.
91. Herron, D.A. 3. Seismic Attributes. In *First Steps in Seismic Interpretation*; Society of Exploration Geophysicists: Houston, TX, USA, 2011; pp. 21–34.
92. Marfurt, K.J. *Seismic Attributes as the Framework for Data Integration throughout the Oilfield Life Cycle*; Society of Exploration Geophysicists: Houston, TX, USA, 2018.
93. Taner, M.T. Seismic attributes. *CSEG Rec.* **2001**, *26*, 48–56.
94. Barnes, A.E. Seismic attributes in your facies. *CSEG Rec.* **2001**, *26*, 41–47.
95. Chopra, S.; Marfurt, K.J. Seismic attributes—A historical perspective. *Geophysics* **2005**, *70*, 3SO–28SO. [CrossRef]
96. Barnes, A.E. Redundant and useless seismic attributes. *Geophysics* **2007**, *72*, P33–P38. [CrossRef]
97. Li, M.; Zhao, Y. Chapter 5–Seismic Attribute Analysis. In *Geophysical Exploration Technology*; Li, M., Zhao, Y., Eds.; Elsevier: Oxford, UK, 2014; pp. 103–131.
98. Liner, C.; Li, C.F.; Gersztenkorn, A.; Smythe, J. SPICE: A new general seismic attribute. In *SEG Technical Program Expanded Abstracts*; Society of Exploration Geophysicists: Houston, TX, USA, 2004; pp. 433–436.
99. Sidney, S. The Back Page; Chen and Sidney (1997) seismic attribute history. *Lead. Edge* **2007**, *26*, 1488. [CrossRef]
100. Huuse, M.; Feary, D.A. Seismic inversion for acoustic impedance and porosity of Cenozoic cool-water carbonates on the upper continental slope of the Great Australian Bight. *Mar. Geol.* **2005**, *215*, 123–134. [CrossRef]
101. Veeken, P.C.; Priezzhev, I.I.; Shmaryan, L.E.; Shteyn, Y.I.; Barkov, A.Y.; Ampilov, Y.P. Nonlinear multitrace genetic inversion applied on seismic data across the Shtokman field, offshore northern Russia. *Geophysics* **2009**, *74*, WCD49–WCD59. [CrossRef]
102. Chopra, S.; Marfurt, K.J. Seismic attributes for prospect identification and reservoir characterization. In *SEG Geophysical Development Series*; Society of Exploration Geophysicists: Houston, TX, USA; European Association of Geoscientists and Engineers: Tulsa, OK, USA, 2007.
103. Lutome, M.S.; Lin, C.; Chunmei, D.; Zhang, X.; Harishidayat, D. Seismic sedimentology of lacustrine delta-fed turbidite systems: Implications for paleoenvironment reconstruction and reservoir prediction. *Mar. Pet. Geol.* **2020**, *113*, 104159. [CrossRef]
104. Zeng, H.; Yuan, B. Seismic sedimentology: Concepts and challenges. In Proceedings of the Beijing 2009 International Geophysical Conference and Exposition, Beijing, China, 24–27 April 2009; Society of Exploration Geophysicists: Beijing, China, 2009; p. 280.
105. Zeng, H.; Hentz, T.F. High-frequency sequence stratigraphy from seismic sedimentology: Applied to Miocene, Vermilion Block 50, Tiger Shoal area, offshore Louisiana. *AAPG Bull.* **2004**, *88*, 153–174. [CrossRef]
106. Zeng, H.; Ambrose, W.A.; Villalta, E. Seismic sedimentology and regional depositional systems in Mioceno Norte, Lake Maracaibo, Venezuela. *Lead. Edge* **2001**, *20*, 1260–1269. [CrossRef]
107. Zeng, H.; Backus, M.M. Interpretive advantages of 90°-phase wavelets: Part 1—Modeling. *Geophysics* **2005**, *70*, C7–C15. [CrossRef]
108. Zeng, H.; Backus, M.M. Interpretive advantages of 90°-phase wavelets: Part 2—Seismic applications. *Geophysics* **2005**, *70*, C17–C24. [CrossRef]
109. Zeng, H. Stratal slicing: Benefits and challenges. *Lead. Edge* **2010**, *29*, 1040–1047. [CrossRef]
110. Zeng, H. Stratal slice: The next generation. *Lead. Edge* **2013**, *32*, 140–144. [CrossRef]
111. Posamentier, H.W.; Kolla, V. Seismic Geomorphology and Stratigraphy of Depositional Elements in Deep-Water Settings. *J. Sediment. Res.* **2003**, *73*, 367–388. [CrossRef]
112. Deiana, G.; Lecca, L.; Melis, R.T.; Soldati, M.; Demurtas, V.; Orrù, P.E. Submarine Geomorphology of the Southwestern Sardinian Continental Shelf (Mediterranean Sea): Insights into the Last Glacial Maximum Sea-Level Changes and Related Environments. *Water* **2021**, *13*, 155. [CrossRef]

113. Gao, M.; Xu, X.; Klinger, Y.; van der Woerd, J.; Tapponnier, P. High-resolution mapping based on an Unmanned Aerial Vehicle (UAV) to capture paleoseismic offsets along the Altyn-Tagh fault, China. *Sci. Rep.* **2017**, *7*, 8281. [CrossRef]
114. Chaves, M.U.; Oliver, F.; Kawakami, G.; Di Marco, L. Visualization of Geological Features Using Seismic Volume Rendering, Rgb Blending and Geobody Extraction. In Proceedings of the 12th International Congress of the Brazilian Geophysical Society, Janeiro, Brazil, 15–18 August 2011.
115. Alves, T.M.; Omosanya, K.O.; Gowling, P. Volume rendering of enigmatic high-amplitude anomalies in southeast Brazil: A workflow to distinguish lithologic features from fluid accumulations. *Interpretation* **2015**, *3*, A1–A14. [CrossRef]
116. Chopra, S.; Marfurt, K. Blended data renders visual value. *AAPG Explor. Geophys. Corner* **2011**, *3*, 38–40.
117. Zeng, H. RGB blending of frequency panels: A new useful tool for high-resolution 3D stratigraphic imaging. In Proceedings of the 2017 SEG International Exposition and Annual Meeting, Houston, TX, USA, 24–29 September 2017.
118. Mohammedyasin, S.M.; Lippard, S.J.; Omosanya, K.O.; Johansen, S.E.; Harishidayat, D. Deep-seated faults and hydrocarbon leakage in the Snøhvit Gas Field, Hammerfest Basin, Southwestern Barents Sea. *Mar. Pet. Geol.* **2016**, *77*, 160–178. [CrossRef]
119. Marfurt, K.; Wen, R.; Zhang, R. 3-D Visualization and Geobody Picking of Amplitude Anomalies in Deepwater Seismic Data. *AAPG Explor.* **2021**, *09*, 10–11.
120. Castanie, L.; Levy, B.; Bosquet, F. VolumeExplorer: Roaming large volumes to couple visualization and data processing for oil and gas exploration. In Proceedings of the VIS 05. IEEE Visualization, 2005, Minneapolis, MN, USA, 23–28 October 2005; pp. 247–254.
121. Chopra, S.; Marfurt, K.J. Detecting stratigraphic features via crossplotting of seismic discontinuity attributes and their volume visualization. *Lead. Edge* **2009**, *28*, 1422–1426. [CrossRef]
122. Castanie, L.; Bosquet, F.; Levy, B. Advances in seismic interpretation using new volume visualization techniques. *First Break* **2005**, *23*, 1365–2397. [CrossRef]
123. Lomask, J.; Guitton, A. Volumetric flattening: An interpretation tool. *Lead. Edge* **2007**, *26*, 888–897. [CrossRef]
124. Dramsch, J.S. Chapter One–70 years of machine learning in geoscience in review. In *Advances in Geophysics*; Moseley, B., Krischer, L., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; Volume 61, pp. 1–55.
125. Karpatne, A.; Ebert-Uphoff, I.; Ravela, S.; Babaie, H.A.; Kumar, V. Machine learning for the geosciences: Challenges and opportunities. *IEEE Trans. Knowl. Data Eng.* **2018**, *31*, 1544–1554. [CrossRef]
126. Bishop, C. *Pattern Recognition and Machine Learning*; Springer: Amsterdam, The Netherlands, 2006; Volume 4.
127. Niyazi, Y.; Warne, M.; Ierodiaconou, D. Machine learning delineation of buried igneous features from the offshore Otway Basin in southeast Australia. *Interpretation* **2022**, *10*, 1–70. [CrossRef]
128. Hoyes, J.; Cheret, T. A review of "global" interpretation methods for automated 3D horizon picking. *Lead. Edge* **2011**, *30*, 38–47. [CrossRef]
129. Liu, M.; Jervis, M.; Li, W.; Nivlet, P. Seismic facies classification using supervised convolutional neural networks and semisupervised generative adversarial networks. *Geophysics* **2020**, *85*, O47–O58. [CrossRef]
130. Wrona, T.; Pan, I.; Gawthorpe, R.L.; Fossen, H. Seismic facies analysis using machine learning. *Geophysics* **2018**, *83*, O83–O95. [CrossRef]
131. Zhang, H.; Chen, T.; Liu, Y.; Zhang, Y.; Liu, J. Automatic seismic facies interpretation using supervised deep learning. *Geophysics* **2021**, *86*, IM15–IM33. [CrossRef]
132. Kumar, P.C.; Sain, K. A machine learning tool for interpretation of Mass Transport Deposits from seismic data. *Sci. Rep.* **2020**, *10*, 14134. [CrossRef]
133. Bugge, A.J.; Lie, J.E.; Evensen, A.K.; Faleide, J.I.; Clark, S. Automatic extraction of dislocated horizons from 3D seismic data using nonlocal trace matching. *Geophysics* **2019**, *84*, IM77–IM86. [CrossRef]
134. Infante-Paez, L.; Marfurt, K.J. Using machine learning as an aid to seismic geomorphology, which attributes are the best input? *Interpretation* **2019**, *7*, SE1–SE18. [CrossRef]
135. Liu, Z.; Song, C.; Li, K.; She, B.; Yao, X.; Qian, F.; Hu, G. Horizon extraction using ordered clustering on a directed and colored graph. *Interpretation* **2019**, *8*, T1–T11. [CrossRef]
136. Peters, B.; Granek, J.; Haber, E. Multiresolution neural networks for tracking seismic horizons from few training images. *Interpretation* **2019**, *7*, SE201–SE213. [CrossRef]
137. Lou, Y.; Zhang, B.; Lin, T.; Cao, D. Seismic horizon picking by integrating reflector dip and instantaneous phase attributes. *Geophysics* **2020**, *85*, O37–O45. [CrossRef]
138. Yang, L.; Sun, S.Z. Seismic horizon tracking using a deep convolutional neural network. *J. Pet. Sci. Eng.* **2020**, *187*, 106709. [CrossRef]
139. Bi, Z.; Wu, X.; Geng, Z.; Li, H. Deep Relative Geologic Time: A Deep Learning Method for Simultaneously Interpreting 3-D Seismic Horizons and Faults. *J. Geophys. Res. Solid Earth* **2021**, *126*, e2021JB021882. [CrossRef]
140. La Marca, K.; Bedle, H. Deepwater seismic facies and architectural element interpretation aided with unsupervised machine learning techniques: Taranaki basin, New Zealand. *Mar. Pet. Geol.* **2022**, *136*, 105427. [CrossRef]
141. Singh, S.; Tsvankin, I.; Naeini, E.Z. Facies prediction with Bayesian inference: Application of supervised and semisupervised deep learning. *Interpretation* **2022**, *10*, T279–T290. [CrossRef]
142. AlRegib, G.; Deriche, M.; Long, Z.; Di, H.; Wang, Z.; Alaudah, Y.; Shafiq, M.A.; Alfarraj, M. Subsurface Structure Analysis Using Computational Interpretation and Learning: A Visual Signal Processing Perspective. *IEEE Signal Process. Mag.* **2018**, *35*, 82–98. [CrossRef]

143. An, Y.; Guo, J.; Ye, Q.; Childs, C.; Walsh, J.; Dong, R. Deep convolutional neural network for automatic fault recognition from 3D seismic datasets. *Comput. Geosci.* **2021**, *153*, 104776. [CrossRef]
144. Laudon, C.; Qi, J.; Rondon, A.; Rouis, L.; Kabazi, H. An enhanced fault detection workflow combining machine learning and seismic attributes yields an improved fault model for Caspian Sea asset. *First Break* **2021**, *39*, 53–60. [CrossRef]
145. Wu, X.; Liang, L.; Shi, Y.; Fomel, S. FaultSeg3D: Using synthetic data sets to train an end-to-end convolutional neural network for 3D seismic fault segmentation. *Geophysics* **2019**, *84*, IM35–IM45. [CrossRef]
146. Yan, Z.; Zhang, Z.; Liu, S. Improving Performance of Seismic Fault Detection by Fine-Tuning the Convolutional Neural Network Pre-Trained with Synthetic Samples. *Energies* **2021**, *14*, 3650. [CrossRef]
147. Di, H.; AlRegib, G. Semi-automatic fault/fracture interpretation based on seismic geometry analysis. *Geophys. Prospect.* **2019**, *67*, 1379–1391. [CrossRef]
148. De Groot, P. Global Seismic Interpretation Techniques Are Coming of Age. *ASEG Ext. Abstr.* **2013**, *2013*, 1–4. [CrossRef]
149. Gao, D. 3D seismic volume visualization and interpretation: An integrated workflow with case studies. *Geophysics* **2009**, *74*, W1–W12. [CrossRef]
150. Paumard, V.; Bourget, J.; Durot, B.; Lacaze, S.; Payenberg, T.; George, A.D.; Lang, S. Full-volume 3D seismic interpretation methods: A new step towards high-resolution seismic stratigraphy. *Interpretation* **2019**, *7*, B33–B47. [CrossRef]
151. De Groot, P.; Bruin, G.; McBeath, K. OpendTect SSIS–Sequence stratigraphic interpretation system. *Drill. Explor. World* **2006**, *15*, 31–34.
152. Sun, T.; Li, H.; Wu, K.; Chen, F.; Zhu, Z.; Hu, Z. Data-Driven Predictive Modelling of Mineral Prospectivity Using Machine Learning and Deep Learning Methods: A Case Study from Southern Jiangxi Province, China. *Minerals* **2020**, *10*, 102. [CrossRef]
153. Johansen, S.; Granberg, E.; Mellere, D.; Arntsen, B.; Olsen, T. Decoupling of seismic reflectors and stratigraphic timelines: A modeling study of Tertiary strata from Svalbard. *Geophysics* **2007**, *72*, SM273–SM280. [CrossRef]
154. Bakke, K.; Gjelberg, J.; Agerlin Petersen, S. Compound seismic modelling of the Ainsa II turbidite system, Spain: Application to deep-water channel systems offshore Angola. *Mar. Pet. Geol.* **2008**, *25*, 1058–1073. [CrossRef]
155. Taufani, L.; Harishidayat, D.; Rohmana, R.C.; Fardiansyah, I.; Purnama, Y.S.; Indriyanto, I.B. *Utilization of Digital Mapping and Outcrop Model to Assess Reservoir Characterization and Quality Index: Study Case from Ngrayong Formation in the Randugunting Block, East Java*; Indonesian Petroleum Association: South Jakarta, Indonesia, 5–8 September 2021.
156. Bakke, K.; Petersen, S.A.; Martinsen, O.J.; Johansen, T.; Lien, T.; Thurmond, J. Seismic modeling of outcrop analogues: Techniques and applications. *Outcrops Revital. Tools Tech. Appl. Tulsa Okla. SEPM Concepts Sedimentol. Paleontol.* **2011**, *10*, 69–86.
157. Lecomte, I.; Lavadera, P.L.; Anell, I.; Buckley, S.J.; Schmid, D.W.; Heeremans, M. Ray-based seismic modeling of geologic models: Understanding and analyzing seismic images efficiently. *Interpretation* **2015**, *3*, SAC71–SAC89. [CrossRef]
158. Grippa, A.; Hurst, A.; Palladino, G.; Iacopini, D.; Lecomte, I.; Huuse, M. Seismic imaging of complex geometry: Forward modeling of sandstone intrusions. *Earth Planet. Sci. Lett.* **2019**, *513*, 51–63. [CrossRef]
159. Harishidayat, D.; Johansen, S.E.; Puigdefabregas, C.; Omosanya, K.O. Compound Seismic Forward Modeling of the Atiart Submarine Canyon Outcrop, Spain: Application to the Submarine Canyon System on the Subsurface Loppa High, Barents Sea. In Proceedings of the American Association of Petroleum Geologists (AAPG)–Annual Conference and Exhibition (ACE), Salt Lake City, UT, USA, 11–13 May 2018.
160. Rohmana, R.C.; Fardiansyah, I.; Taufani, L.; Harishidayat, D. Depositional processes and facies architecture of Balikpapan sandstone formation, application of 3D Digital Outcrop Model (DOM) to identify reservoir geometry and distribution in deltaic system. *Sci. Contrib. Oil Gas* **2019**, *42*, 35–42. [CrossRef]