Middle Mesozoic to Present Geological Evolution of the Central-Northern Sector of the Falkland/Malvinas Plateau as Inferred from Seismic Data

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Abstract

The sequence stratigraphy is a methodology that, by means of the recognition of depositional sequences in stratigraphic architecture, reconstructs tectonic phases and relationships between tectonic, sedimentation and eustasy.
A seismo-stratigraphic study of the northern sector of the Falkland Plateau (FMP) is derived from integrated analysis of two unpublished seismic reflection profiles combined with published seismic profiles, bathymetric and well data. Data analysis allowed the identification of an acoustic basement, four seismic sequences (A to D) and their bounding unconformities (r1, r2, r3 and r4), aged from middle Jurassic to Present. The precambric acoustic basement, bounded by r1 unconformity, overlain by the Middle-Late Jurassic syn-rift continental deposits of sequence A, which is bounded at the top by the r2 unconformity, testify a tectonic behaviour of uplift around the Jurassic/Cretaceous boundary. The overlying sequences B and C represent the post-rift phase. From the late Cretaceous up to Cretaceous/Paleogene boundary, a widespread erosion in the northern part of the FMP is suggested by the r4 unconformity cutting the underlying sequences C and B. The erosion is probably due to a southward tilting linked to underthrusting of the southern sector of the FMP. The lower and constant thickness of sequence D suggests, during the Cenozoic, a slow rate of subsidence, probably linked to the contemporaneous stop of the subduction of the FMP under the Scotia Plate.

1 Introduction

The sequence stratigraphy is based on the principle according to which the sedimentary successions are interpreted as the result of the interplay of three independent variables: eustatism, tectonic (uplift and subsidence) and sediment supply. This interaction leads to cyclical variations in sea level, the stratigraphic evidences of which are sedimentary bodies or depositional sequences, bounded at the bottom and the top by unconformity and correlative conformity (sequence boundaries), considered

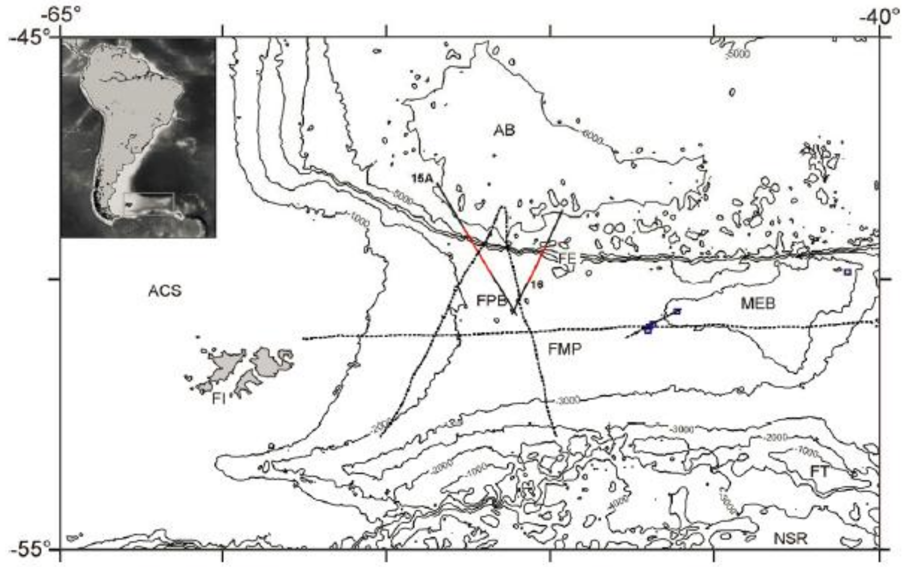

Figure 1: Bathymetric map and localization of analyzed unpublished (continuous lines) and published (black dot lines) seismic profiles (References listed in [1]). The blue squares indicate the position of DSDP Leg 36 and Leg 71 wells. In red the portions of seismic profiles shown in Figures 2 and 3. AB: Argentine Basin, ACS: Argentine Continental Shelf, FE: Falkland Escarpment, FI: Falkland Islands, FPB: Falkland Plateau Basin, FMP: Falkland-Malvinas Plateau, FT: Falkland Trough, MEB: Maurice Ewing Bank, NSR: North Scotia Ridge.

to be synchronous at global scale. These surfaces are easily recognizable in the seismic sections, where they appear as discrepancies between geometric surfaces and lateral terminations of seismic horizons. In offshore areas, using the principles of sequence stratigraphy for the interpretation of seismic reflection profiles, is possible, with the integration of well data, recognize and reconstruct the depositional sequences and depocenter and their migration in the time and space, allowing kinematic reconstruction of the tectonic structures, with the relative growth rates, and then establishing a chronology of geological events.

For the study described in this paper, a comparative analysis, based on two unpublished seismic profiles, published seismic reflection and refraction profiles, bathymetric and well data, was carried out, aimed to identify seismic-stratigraphic sequences and main unconformities correlative in the central-northern Falkland Plateau Basin (FPB) in order to determine its evolution history during the main phases of the South Atlantic Ocean opening. The FPB is a portion of Falkland/Malvinas Plateau (FMP), which is morphologically a broad, V-shaped eastward extension of the Argentine continen-

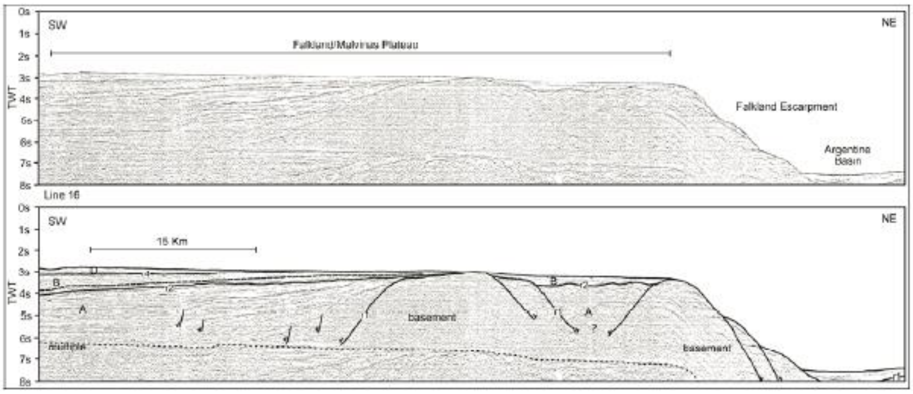

Figure 2: Portion of seismic reflection line 16 on the northern sector of the Falkland Plateau Basin and the southern part of Argentine Basin, and its interpretation (relative position in Figure 1). The deep depocenter and the faults affecting the basement in the Falkland Plateau Basin and escarpment are clearly visible. The syn-sedimentary faults in sequences A and the numerous diffraction hyberbolae characterizing the acoustic facies of the basement in the Falkland Escarpment are visible. The main unconformities are clearly recognizable: r1 unconformity is the basement top of Precambrian age; r2 is an unconformity which extends from the upper Late Jurassic to the lower Early Cretaceous; the dot line in B sequence represent an upper Early Cretaceous discontinuity; the r4 unconformity develops at the Cretaceous-Paleogene transition. Vertical scale in TWT seconds. For the description of the different A to D sequences, see text.

tal shelf (ACS). The FMP is bounded to the north by the steep slope of the Falkland Escarpment (FE), which corresponds to the Agulhas-Falkland Fracture Zone (AFFZ), to the south by the Falkland Trough (FT), and to the east by the Maurice Ewing Bank (MEB) (Figure 1).

In the last decades, the region has been the object of numerous investigations for scientific purposes, focused on the nature of the FMP basement. Several authors (e.g. [2] and references therein) affirm that it consists of a thinning continental crust (12 to 16 km), although the hypothesis of a basement formed by subaerial ocean spreading is not excluded ([3] and references therein).

2 Regional geological setting

It is note that the FMP evolution history is closely linked to the Gondwana break-up and the South Atlantic Ocean opening. Ben-Avraham et al. [4, 5] recognize a “pre-rift” phase (Permian-Late Triassic), during which buoyancy forces, produced by large mantle plumes, around the present day Bouvet triple junction, played an important role in the activation of strike-slip fracture systems accompanying to south-

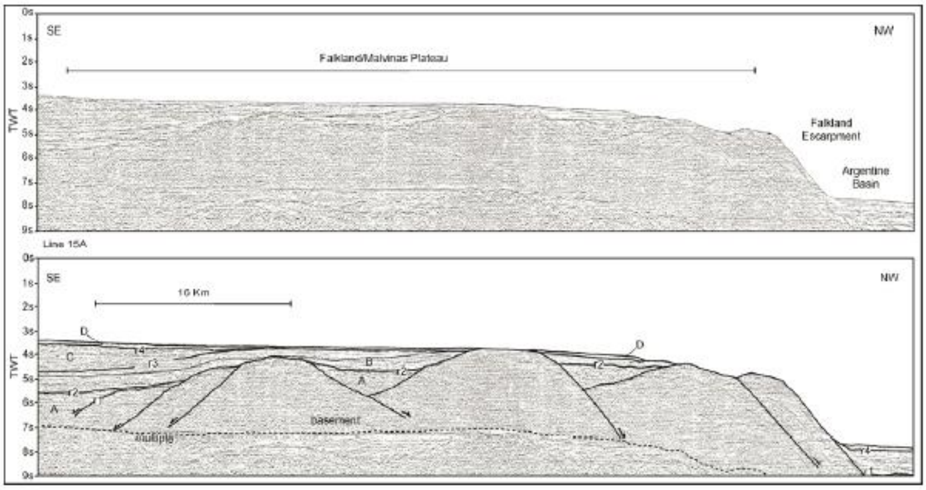

Figure 3: Portion of the seismic reflection line 15A on the northern sector of the Falkland Plateau Basin and the southern part of Argentine Basin, and its interpretation (relative position in Figure 1). It is possible to note the faults affecting the basement and forming small basins in proximity of the Falkland Escarpment. The main unconformities are clearly recognizable: r1 unconformity is the basement top of Precambrian age; r2 is an unconformity which extends from the upper Late Jurassic to the lower Early Cretaceous; the dot line in B represent an upper Early Cretaceous discontinuity; r3 is a Late Cretaceous unconformity; the r4 unconformity develops at the Cretaceous-Paleogene transition. Vertical scale in TWT seconds. For the description of the different A to D sequences, see text.

ern Gondwana break-up. Others authors describe an "early syn-rift" phase (Late Triassic-Early Jurassic) in which evidence of crustal block rotations and subsequent basal volcanism, generated by strike slip faults systems which also caused the following AFFZ development, are found in the South Africa Kaapvaal Craton. The subsequent "syn-rift" phase, which lasted up to the Late Cretaceous, is generally subdivided in four steps ([6] and references therein). In the first one, which covers the upper Early Jurassic, a splitting up of Southern Gondawana took place with a consequent opening, in the Middle Jurassic, of several basins all localised crosswise over the proto-Atlantic ocean margins [7]. At the Jurassic/Cretaceous boundary the new southern American and Southern African margins, with several shelf basins controlled by strike-slip fault systems, start to be outlined. Contemporaneously the FMP (South America) and the Agulhas Plateau (South Africa) take shape through the AFFZ activation [6]. During the Early Cretaceous the South Atlantic Ocean starts its formation throughout the southern mid-Atlantic Ridge activation. [8], At the Late Cretaceous, the FMP and Agulhas Plateau definitively separated ([8] and references therein). According to the evolution history of the South Atlantic Ocean, in the Falkland Plateau Basin (FPB), the marine sedimentation starts at the Late Jurassic and several studies have proposed that the FPB, filled with more than 7000 m of sediments, presents a variable depth and deepens from north to south (e.g [9] and references therein). Its depocenter is located near the Falkland Trough (FT) (Figure 1), an E-W depression generated from the active leftlateral strike-slip fault, which marks the South America-Scotia plates boundary and separates the FPB from the North Scotia Ridge ([10] and references therein).

3 Material and methods

The two unpublished multichannel seismic reflection profiles here analysed (15A and 16), collected during an Argentine-Uruguay Reconnaissance Seismic Survey (1977) in the northern area of the FPB, sum a total of about 490 km, and are oriented NW-SE and NE-SW respectively (Figure 1). The seismic profiles were available only on paper record. Some published seismic reflection and refraction profiles [11, 12, 13], collected within or very near to the study area (Figure 1, black dotted lines), were also utilized to complete the seismostratigraphic analysis, which was integrated with published well data reports. The wells were drilled on the MEB in the 1977 and 1980, during DSDP Legs 36 and 71 (sites 327A, 329, 330A, 330 and sites 511, 512A, 512 respectively, Figure 1: blue squares). All boreholes recover the sedimentary units, but only hole 330 reaches the acoustic basement, visible in the published seismic profiles [12]. A seismic-stratigraphic interpretation was carried out on the profiles using standard procedure. The seismic sequences, constituted by a relatively conformable succession of seismic reflectors, are distinguished on the basis of top and base bounding unconformities and their correlative conformities, and are interpreted on the base of their internal reflector geometries ([14] and references therein).

4 Seismo-stratigraphic interpretation

Based on the seismic profiles analysis, the stratigraphic succession is composed of an acoustic basement (BS) overlain by four seismic sequences (A to D), bounded by relative unconformities (r1, r2, r3 and r4). The BS, all recognized seismic sequences and their boundaries, were correlated in the studied FPB sector, by means of interpolated published seismic profiles (Figure 1). Although there are some uncertainties in our analysis, our interpretations are underpinned by the high continuity and reflectivity of the main discontinuities correlated all across the studied FPB area.

Basement The top of the acoustic basement is defined by the r1 unconformity, detected on the unpublished seismic profiles, which represents an erosional surface (Figures 2 and 3). Numerous strong diffraction hyperbolas, testifying a strong contrast of acoustic impedance, mark this unit in certain sectors, in particular along the FE, where it crops, fractured and dislocated by high-angle normal faults, that define grabens and half-grabens (Figures 2 and 3). South of FE the basement deepens and the FPB depocentre is filled by the overlying seismic sequence A (Figures 2 and 3). The acoustic facies of this unit is characterized by a chaotic configuration.

Sequence A Above the r1 unconformity, the basal seismic sequence A shows subparallel to divergent internal configurations (Figure 2). The vertical thickness of sequence A varies greatly along the studied profiles; it is thickest near the faults that control the depocenters of the depressions. However, it disappears or becomes rather thin on the structural highs (Figures 2 and 3). Some reflectors within sequence A are interrupted and dislocated by direct faults (Figure 2). Because these faults involve neither the more superficial reflectors of the sequence nor the overlying units, they are believed to be sinsedimentary faults. The upper boundary of sequence A is the r2 unconformity, which cuts the reflectors lying below and shows a very high amplitude, dipping steeply southward as for the r1 unconformity (Figure 2).

Sequence B Seismic sequence B lies in angular unconformity above the r1 and r2. This sequence is characterized from a parallel internal configuration (Figure 3). Also the sequence B is absent or extremely thin on the structural highs of the basement (Figures 2 and 3). At the south this sequence is characterised by a slight dipping and thickening (Figure 2). The r3 unconformity represents the upper boundary of sequence B (Figure 3), and generally cuts sequence B reflectors, preserving, as the r2, a southward gently dip (Figure 3).

Sequence C The seismic sequence C onlaps r2 and r3 unconformities and often shows an hummocky internal configuration (Figure 3). It has a spread and moderate thickness, presenting a slight southward inclination (Figure 3), whereas it is practically absent near the FE, most probably due to strong active erosion (Figures 2 and 3). The top of sequence C corresponds to the r4 unconformity, which is a very marked reflector easily traceable throughout the area, where it tends to be subhorizontal, contrary to the boundary of the other sequences observed (Figures 2 and 3). This unconformity truncates the underlying sequences B and C, sometimes leading to their complete elision, as can be seen near the southern margin of the FE (Figures 2 and 3).

Sequence D The overlying seismic sequence, indicated as D, extends from the r4 unconformity to the ocean floor (Figures 2 and 3). This sequence is characterized by a parallel internal configuration (Figure 2). The morphological evidences show an erosion of sequence D, this erosion some time reaches the r4 unconformity and suggests an active ocean floor erosion (Figures 2 and 3).

5 Discussion

The acoustic basement detected in the seismic profiles was interpreted from the interpolated DSDP site 330 hole data, as constitute of continental nature (crystalline basement), with a Pre-cambrian age [12, 11], and with the north FMP margin (FE in Figure 1) interpreted as a continental-oceanic contact by Rabinowitz and LaBrecque [15] and by Lorenzo and Wessel [16].

However Ludwig [17] and Barker [3] affirmed that in the central FMP the basement is not simply characterized by continental crust, as an extension of the ACS, but a thicker oceanic crust, representing a zone of transition between a continental scarp and an aborted ocean basin. Also the gravimetric and magnetic data observed in this area [1, 18], coupled with the observed oceanic crust samples (gabbros and olivine basalts) dragged at sea-floor along the south FE [13], suggest that the nature of the acoustic basement, in a restricted area south of FE could be different from a continental one. On the other hand, going south, despite the poor resolution of seismic data, the seismic facies analysis, together with gravimetric data analysis, suggest again a possible continental nature of the basement [1, 18]. These findings could be the expression of crustal fragments of different nature that could be split and dragged from proto-Atlantic margins during the activity of AFFZ [19].

The age and nature of sediments within seismic sequences and their boundaries were calibrated with borehole data. The top of BS, r1, interpreted as an erosional surface unconformity, could corresponds to pre-Cambrian U1 unconformity of Lorenzo and Mütter [13].

The overlying sequence A can be correlated to continental and shallow marine water deposits (black shales) found at Site 330, on the western flank of the MEB [12, 11], varying in age from Middle Jurassic to upper Late Jurassic (unit D1, [13]). Sequence A fills the major depressions in the area, and it is thought that this sequence was deposited during the first phases of crustal extension due to the initial Gondwana break-up, prior to the opening of the Southern Atlantic Ocean, which led to the development of an accommodation space in the basin ([6]). The growth faults observed within this sequences (Figure 2) show a maintenance of accomodation space during its deposition. The top of sequence A is marked by the r2 unconformity, which has been related with the U2 unconformity of Lorenzo & Mütter [13], varying in age from upper Late Jurassic to lower Early Cretaceous. So the r2 unconformity corresponds to an important erosional surface developed at the same time of the regional thermal uplift and activation of the AFFZ, which accompanied the Gondwana break-up [8, 6].

Sequence B, which lies in angular unconformity above the basement and sequence A, has been related to the D2 sequence, varying in age from middle Early Cretaceous to lower Late Cetaceous [13]. This sequence is characterized by shallow (black shales) to deep marine deposits [12, 11]. Finally the increasing thickness of sequence B in the FPB suggest the fast sinking of the studied area [12, 11, 20]. The marked reflector within the sequence B (dot line in B sequence, Figure 2), could be related with the change from shallow (black shales) to deep marine sedimentation evidenced in D2 sequence occurring at the late Early Cretaceous [13]. This change is thought to be related to the activity of new bottom currents within the deeper oceanic basin, developed in relation to the initial opening of the South Atlantic Ocean [11, 6]. The top of sequence B is delimited by the r3 unconformity (Figure 3), correlated to the U3 unconformity, dated from upper Early Cretaceous to middle Late Cretaceous and interpreted as a strong erosional contact linked to a lower Late Cretaceous uplift ([13]). The uplift is thought, by the same authors, to be induced from the input of heat from an oceanic ridge passing along the AFFZ.

Above the r3, the seismic sequence C can be correlated with the Late Cretaceous pelagic sediments of D3 sequence of Lorenzo and Mütter [13]. The sequence C, ending at the upper Late Cretaceous, is bounded in the upper part by the regional r4 unconformity (Figure 3). This unconformity has been correlated with the U4 unconformity, attributed to Southern Atlantic Ocean bottom currents (i.e.Del Ben and Mallardi [9] and references therein). However our seismic profiles show evidence

(Figure 3) that at south of FE, the r4 unconformity cuts a deformed sequence B and r3 unconformity, suggesting that, at the Cretaceous/Paleogene boundary, the area experienced uplift, with consequent partial erosion along the FE area. At the same time an ongoing subsidence is still affecting at south as testified by the major thickness of sequence C and by the pelagic nature of correlated sediments (unit D3 of [13]). Subsidence and relative uplift at north of this area, is in agreement with the contemporaneous active transpressive system bounding the South America and Scotia plates, which produced the underthrusting, and consequent southward tilting, of the southern FMP ([9] and references therein). Sequence D, overlying the r4 unconformity, has been correlated to drift depositional sequences (D4 and D5 of [13]) with a sedimentation characterized, for the entire Cenozoic period, by marine shelf and pelagic sediments, due to the most recent phase of the South Atlantic spreading. Within sequence D, an irregular development of marked reflectors was found (Figure 2). Such surfaces, correlated to the U5 unconformity of Lorenzo and Mütter [13], are probably linked to the activity of strong circum-polar currents activated after the Drake Passage opening at the Eocene-Oligocene transition (e.g. [21] and references therein). Finally, it is possible to notice that the sequence D, deposited in a time interval longer than sequence C, shows respect to it a lower and constant thickness cross over the studied area, except for the morphological highs. This finding suggests that the area, during the Cenozoic, underwent a decreasing of the subsidence rate, and supports the known change in the tectonic regime of the FMP occurred at about Late Miocene, when the northward migration of the North Scotia Ridge ceases and the seafloor spreading stops in the Central Scotia Sea ([22] and references therein).

6 Conclusions

The aim of this work was to reconstruct the seismo-stratigraphic of the depositional history of the central-northern FPB sector, in order to analyze and compare its geological evolution during the main phases of the Africa-South America separation and the subsequent South Atlantic opening.

Four seismo-stratigraphic sequences and four main unconformities have been recognised, interpreted and correlated throughout the studied area.

During the Permian-Late Jurassic pre-rift tectonics, the acoustic basement, correlated throughout the r1 unconformity, undergone to a phase of erosion, probably due to the thermal uplift.

Subsequently, during the Middle Jurassic, time in which the proto-Atlantic initiated its opening with consequent developing of several depressions positioned crosswise over the margins, the FMP basins formed, characterized by continental deposits, as testified by DSDP well data on the MEB.

At the Jurassic/Cretaceous boundary, the r2 unconformity highlights a tectonic behaviour of uplift. Whereas the thickness of sequence B, characterized by marine sediments, suggests the geological evolution of basin from the beginning of Early up to the Late Cretaceous, under the continuing Gondwana break-up and developing of AFFZ phases.

During the Late Cretaceous, as known from literature, this area underwent a strong southward tilting interpreted as a lower Late Cretaceous thermal uplift, linked to the migration of the oceanic ridge along the AFFZ, evidenced, from well data, by probable hiatus occurring in this time interval.

The marked erosional unconformity r3 is probably an expression of this tilt. At the end of Late Cretaceous the studied sector is still continuing its subsidence, as testified by the thickness of sequence C and by its correlation with pelagic sediments from well data. Also if contemporaneously the FE area at north of the studied sector is still experiencing uplift, as seen by the thinning and planning of sequence C thickness on this area, with a consequent partially erosion, testified by the r4 unconformity cutting the r3 unconformity and the deformed sequence B.

Subsequently, during the Cenozoic, this area undergone to positional behaviour characterized by marine sedimentation deposited at a slower rate of subsidence, as testified by the lower thickness of sequence D with respect to sequence C. This decrease of the accommodation space is attributed to the known change in the tectonic regime of the southern FMP margin, which passes from an oblique subduction to a clearly transform regime.

Finally it was found that the basement, in a restricted area south of the FE, is not clearly characterized by continental crust. Future studies will be aimed to underpinning such hypothesis and investigate the origin of the basement in this area, which may be linked either to a spread of basaltic volcanism occurred during the early phase of the Gondwana break-up, or to a process of split and dragging of different crust fragments during the early activity of the Agulhas-Falkland Fracture Zone.

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