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Author : **Bryn Austin**

Approved : **M Postle-Hacon**

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Hydrosearch Associates Limited
Goldsworth House
Denton Way, Goldsworth Park
Woking, Surrey GU21 3LG U.K.
Tel : +44 (0) 1483 746500
E-mail : info@hydrosearch.co.uk
Fax : +44 (0) 1483 746505

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Principal Investigator : Bryn Austin, Brynterpretation Limited

Associate Investigator : Dr. Brian O'Reilly, DIAS, Dublin
Project Mentor : Prof. Pat Shannon, University College, Dublin

Drawings : Marnie Whyte, Hydrosearch Associates Ltd.
Geodesy : Mike Postle-Hacon
Mapping : Chris Ward, Neil Webster, Marnie Whyte
Seismic Data Processing : Richard Logsdaile
Data Management : Julie Gale, Pam Ellis, Kai Green
Project Management : Brynterpretation Limited and HAL

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EXECUTIVE SUMMARY

As part of the continuing RSG Research programme it was decided to carefully interpret the upper portions of existing exploration 2D seismic data to investigate aspects of the instability of the continental slope in a region of the NE Irish Rockall Basin. The region was selected since previous regional study using TOBI sonar and basin-wide seismic interpretation of the Tertiary geology suggested large scale (10 's of km) features exist that are thought to result from instability of the slope through geological time.

Features recognised range from linear faults and bathymetric scarps, mass movement slides, recent faulting and erosive canyon-valley systems. Further investigation through more detailed description and study of such features, (which lie at or just beneath the seabed), could therefore allow research to progress concerning the process mechanisms and importantly, the frequency and time scale at which the slope becomes unstable.

The overall objectives of the project were to identify and define the extent of individual slope failure features and canyons by mapping and profile creation. It was hoped to constrain the three-dimensional geometry of the features and attempt to evaluate the likely controls on their formation.

The investigation used the large RSG seismic database (~7000km) together with available gravity core samples and the results from the shallow drilling location 11/20 sb01 as well as what top-hole information that exists from the two exploration wells drilled within the region. The investigation also benefited strongly from the unified Neogene stratigraphical study contained in the RSG Project 00/5 report. This supported the ambitious targets of the investigation allowing them to be achieved successfully through use of the sound correlation framework available for detailed interpretation of particular features of interest. The investigation has successfully identified and mapped several important features critical to understanding the stability of the shallow subsurface in the NE Rockall region. The features are displayed by reference to forty fully interpreted data examples and maps. The accompanying text is intentionally brief, reporting the observations made during the investigation together with results and conclusion that stem from the observations. Recommendations for further analysis and study plus limited new data, such as age dating and higher resolution seismic, are made throughout the report.

1. INTRODUCTION

The report presents detailed seismic interpretation of the seismic dataset available to the Rockall Studies Group (RSG). This has been integrated with the RSG-funded TRIM (TOBI Irish Rockall Margin) dataset in order to investigate slope failure features in the NE region of the Irish sector of the Rockall Basin. The sedimentological analysis of a single RSG gravity core in the region, (out of the 10 existing RSG gravity core samples) was also made available for the investigation.

The work builds upon the regional RSG Project 98/23, (Rockall Trough Shallow Stratigraphic Framework and Geohazards Study, Austin 2000). Furthermore this report benefits from the interpretation and synthesis of the late Palaeogene and Neogene succession in RSG Project 00/5. Interpretation and mapping of the seismic data available for the investigation began during May 2001.

Initial attempts to reprocess four higher resolution seismic lines yielded disappointing results due to several factors including navigational instability and low bandwidth. These data had been acquired specifically to target the complex and heavily dissected southern part of the area. Because of this and in order to meet the objectives of the investigation, the original area of investigation needed to be increased some 40 km northwards in order to:

a) Maximise input from the RSG shallow borehole 11/20-sb01 area with its two local sparker and airgun grids.

b) Utilise observation and investigation of the Donegal Canyon system to better understand the severely eroded southern area.

Bryn Austin, (Brynterpretation Ltd.), carried out the principal interpretation and reporting with input from Dr. Brian O'Reilly for the Dublin Institute for Advanced Science (DIAS). Professor Pat Shannon, University College Dublin (UCD) is the mentor for Project 00/6.

1.1. Acknowledgements

This publication uses data and survey results acquired during a project undertaken on behalf of the Rockall Studies Group (RSG) of the Irish Petroleum Infrastructure Programme Group 2. The RSG comprises: Agip (UK) Ltd, Anadarko Ireland Company, ARCO Ireland Offshore Inc, BG Exploration & Production Ltd, BP Exploration Operating Company Ltd, British Borneo International Ltd, Elf Petroleum Ireland BV, Enterprise Energy Ireland Ltd, Mobil Oil North Sea Ltd, Murphy Ireland Offshore Inc, Phillips Petroleum Exploration Ireland, Saga Petroleum Ireland Ltd, Shell EP Ireland BV, Total Oil Marine plc, Union Texas Petroleum Ltd, and the Petroleum Affairs Division of the Department of the Marine and Natural Resources.

2. OBJECTIVES AND METHODOLOGY

2.1 The overall objectives of the project were to identify and define the extent of individual slope failure features and canyons within a large area of the NE Rockall Basin where previous work has shown that such features are optimally developed, O'Reilly et al 1999, Austin 2000. It was hoped to constrain the three-dimensional geometry of the features and to evaluate the likely controls on the formation of some very large seabed mass wasting features and the slope in general.

The original area chosen (**Figure 1**) lies within the rectangle formed by the co-ordinates:

Lower left hand corner	:	54° 40.0' North	011° 35.0' West
Top right hand corner	:	55° 27.0' North	010° 00.0' West

The same Projection conventions as used in the 98/23 Report will allow accurate correlation of the seismic database and the TRIM mapping and reporting. These are:-

Projection:	Universal Transverse Mercator
Zone:	28 North
Spheroid:	International 1924
Central Meridian:	15° 00' 00" West
Map Sheet Datum:	European Datum 1950, Common Offshore.

2.2 The investigation methodology adopted involved the integration of the various geophysical and geological datasets available for the project. The proposed methodology for the work was as follows:

2.2.1 Integration of existing available 2D seismic data with the NIOZ acquired seismic dataset. Unfortunately, the unavailability of the older NIOZ data, (and major problems in navigation and seismic bandwidth of the NIOZ 2000 higher resolution seismic data, specifically acquired for this investigation), meant that the seismic dataset was largely limited to the commercial seismic dataset available to the RSG.

2.2.2 Integration of the industry seismic data with higher resolution RSG Challenger shallow seismic dataset and gravity cores around the 11/20-sb01 borehole site in order to build upon and develop where possible the results from the previous UCD work (Praeg and Shannon 2000). The RSG Challenger higher resolution seismic could not physically be loaded into the digital seismic database as originally envisaged. Only .jpg files of parts of the lines were made available towards the end of the Project. This meant that only very limited integration was possible, resulting in more difficult and intrinsically less confident interpretation.

2.2.3 Close collaboration should be maintained with RSG Projects 00/01 and 00/17 in order to obtain ground-truth data from the available gravity cores. Any available preliminary geological descriptions from the gravity cores in the region were to be utilised in attempting to correlate the seismic data with the results from TRIM.

2.2.4 Integration of the final interpretation results of the TRIM dataset during the interpretation of the seismic data in the area of study and rationalise any discrepancies found therein.

2.2.5 Construct an integrated set of maps and sections showing seabed and subsurface structure with particular reference to seabed slope geometry and mass wasting features.

3. GEOPHYSICAL DATABASE

The geophysical database comprises all the seismic data in the RSG/PIP2000 seismic database the location of which is shown in **Figure 2**. This is the same as used for RSG Project 98/23 plus many line kilometres of additional data, (especially as strike lines along the slope), supplied by the RSG members. In total this represents some 7000 line km of exploration 2D seismic data and is the same as used during RSG Project 00/5 Stratigraphic Study. Acquisition sample interval is 0.002sec conventionally processed to 0.004 sec; trace interval is generally 25m. The digital seismic data and interpretation is contained in Landmark Project *'piphydro'* residing at Phillips and at HAL.

In addition to the exploration seismic, four lines of higher resolution data were acquired by NIOZ (lines STRAT-06, -07, -08 & -09) to provide a loop of good resolution data in the vicinity of the 'T' Canyon, **Figure 2**. As shown in **Figure 25** the data are noisy and unfortunately contain too few higher frequencies, Logsdale 2001. They are also misleading to the investigation in that the navigation is obviously suspect compared to the remainder of the digital geophysical database.

The useful BGS Challenger sparker and airgun higher resolution lines acquired over and adjacent to the Shallow Drilling Borehole 11/20–sb01 site are available on CD's as .jpg files but do not form part of the database for the investigation as was originally envisioned.

4. GEOLOGICAL DATABASE

Age-dated samples from the RSG borehole 11/20–sb01 site exist down to 11.5m subseabed. No further geological borehole data were available in the area of investigation. However, use has been made of the scattered borehole data that exist in the greater Rockall Basin through the integrated stratigraphic framework described elsewhere, (Stoker 2000, Austin 2000 and Austin 2001b).

Although usually only containing surficial material the RSG Challenger gravity cores in the vicinity of the 11/20-sb01 site are included in the geological database. These are currently being studied by research students at UCD (Ovrebo et al. 2001a). The single gravity core that has a sedimentary description is the SC001 core that penetrates just 1.1m into the seabed. Two piston core descriptions containing surficial material acquired by NIOZ are also included in the database located in the near abyssal depths of the lower 'T' Canyon.

Data from the fairly numerous other gravity core locations noted on the attached maps have not been used in the investigation. Their origin is from the Geoboy Geochemical focussed sampling campaign conducted along the Atlantic Margin during 1990/91.

Several gravity or piston cores were collected during the Logachev TTR-8 Cruise over the extreme SE portion of the area of investigation. These were mainly located at the shelf break (in relatively shallow waters) with just a few in upper and mid slope environments. The core descriptions have been studied but as expected were found only to contain surficial/seabed information which has only very limited relevance to the other datasets available during this investigation and they have therefore been omitted from the maps for clarity.

5. REGIONAL STRUCTURE and STRATIGRAPHY

The NE Rockall region is recognised as being under explored and structurally quite complex, (**Figures 4a & 4b**). This can be seen in the first instance from a glance at the bathymetry and slope gradients (**Figures 5 & 6**). Severe indentations occur, eating into the slope to disrupt the smoother trend of contours both up on the shelf and also down at near-basin floor depths. An extensive system of young faults exists, actively cutting up to the seabed, as do contour-hugging scarp features also generated along more ancient and longstanding fault lineaments. These occur orientated generally parallel to the slope as can also be clearly seen. The geoseismic profiles are located in **Figure 4c** and provide an overview of the geological complexity of NE Rockall where each line shows quite surprising dissimilarity in terms of structure, slope geometry and often stratigraphy to adjacent profiles.

The general lack of lithological and age data means that the stratigraphic framework is poorly constrained. From those samples that are available, however, there is still a severe lack of Palaeogene and Neogene age dating. The Cenozoic stratigraphy of the NE Rockall region has, however, quite recently been addressed as RSG Project 00/5 and a unified seismic stratigraphy has been established over large parts of the region with a fair to moderate degree of confidence, Stoker et al. 2001, Austin 2001a. **Figure 3** is taken from that report and shows how the Tertiary strata may be defined as at least four Megasequences RT-d, RT-c, RT-b and RT-a. These are all bounded by regionally correlateable unconformity surfaces. The surfaces have been correlated seismically across the basin more or less from west flank to east flank. They extend elsewhere for considerable distances, (e.g. as far as the Faroes and potentially even Northern Norway). These facts increase the confidence and soundness of the stratigraphic framework and ensuing model for an investigation such as this.

The geoseismic profiles shown as **Figures 4a & 4b** run from shelf to abyssal depths and provide a good overview of the shallow structural geology. They are colour coded as to the Megasequences and regional unconformities denoted as BTU (Base Tertiary Unconformity), C30 (late Eocene), C20 (early Miocene and C10 (early Pliocene). It is thought that the BTU in many places appears to comprise of volcaniclastic and igneous material both above and below the aggressively angular, erosive regional unconformity. This interpretation is based upon regional observation of the variable and often chaotic character of the seismic data at BTU level together with the associated amplitude contrasts that have been correlated to the inferred sill-like bodies, cones and other volcanic centres. These are known to exist from magnetic data, TOBI interpretation, recovered gravity core samples as well as shallow borehole information, e.g. **Figures 13-15, 17-19, 21, 29, 34** and Haughton et al 2001. The geoseismic profiles show that the C10 unconformity is similarly angular and cuts down into the BTU but little evidence exists, within the region, of volcanic activity associated with the C10 surface.

The interpreted seismic line shown as **Figure 8** runs along / sub parallel to the slope. It shows how an otherwise smooth upper slope/ outer shelf environment with much sub-parallel bedded internal reflectivity is eroded and eaten into. Several stages of destructive structural as well as gross depositional activity, (with consequent ensuing slope instability), can be inferred by the features identified.

Much large scale dominantly down-to-the-basin faulting occurred in the NE Rockall region during the Mesozoic. Reactivation along these pre-existing lineaments, as well as newer movements, is believed to have occurred since (**Figure 8**). It is important to note, however, that the profiles show a younger set of faults occurred *post the BTU* presumably as the result of subtle changes in major stress orientations as identified in other parts of the Atlantic Margin (**Figures 8, 10, & 12,** Austin 2001 or Dore 2000). Although not always the case in these data examples it is interpreted elsewhere in a majority of cases that the younger faults often tip above or have decolled at or close to the BTU surface, (**Figures 10 & 11**). The younger faults show a range of relatively low angle dips with several examples of extremely low angle, shallow faulting creating 'scallop' shaped depressions at the seabed, **Figure 10**. The faults shown here clearly cut through Megasequences RT-a and RT-b in which they appear to tip. The seismic line shows very little, if any effect of compressional activity that might be expected to occur at the downslope termination of the features. This appears to be an interesting characteristic since although compressional evidence was actively searched for none was in fact clearly discernible from the thousands of kilometres interpreted during this investigation. Only in the heavily canyoned, southern portion of the investigated region, in great water depths of 2000m plus was there much evidence of a 'hummocky terrain' -as interpreted from the diffractive nature of the seismic data, that might be expected from large scale “failure slabs” or side wall slumping. Such observation needs to be investigated more fully than could be accommodated during this investigation since it relates to fundamental issues and debate regarding generation, timing and mechanisms. Through such observation we can hope to explain the present day slope architecture, which shows such large scale destruction through the links with the obvious instability created by the ongoing fault activity of the slope margin. There are also, however, examples of apparent slope instability that do not necessarily appear to been caused *directly* by faulting, **Figure 11**. The better understanding of the process of generation and sustainability of slope canyon/ valley systems through, (possibly extensive periods of) time, is another means to appreciate the risk of seafloor instability in the slope setting, **Figures 13 – 15**. What are the real relationships and links between catastrophic slide generation, slab failure, canyon/valley development and the mechanisms of faulting? Does the observed extensive contourite current activity act as a catalyst to other slope processes by eroding /over-steepening slopes as well as by overloading the slope in places by upslope accretion?

Although faulting is considered here as the fundamental, major driver mechanism, so many unanswered questions still remain due to lack of seismic resolution in any attempt to link all the facets involved in leading to an assessment the stability of the of seabed slope. The dataset here cannot, for example, detect the important high frequency down slope processes such as creep and low order sediment flow. These are also considered, from evidence elsewhere, to aid in slope destruction and can build up to help initiate instability on the engineering timescale meant here as the lifetime of an oil or gasfield.

6. IMPORTANT FEATURES INDICATING SLOPE DESTRUCTION

Several seabed and subseabed features such as major fault, canyon, and slide systems have been identified and mapped regionally over large parts of the Rockall Basin. They are considered to provide the principal gradient increases, local stress regimes, abrupt changes in pore pressure and other geotechnical elements such as ease of liquefaction in some contourite sediments and other linking mechanisms / influences that allow slope instability. As part of the investigation these major morphological features have been interpreted using the data available and are described below.

6.1 Erris Fault Scarp

The Erris Fault System or Zone (ERZ) displays large (km scale) heave dimensions as well as lateral dimensions covering much of N.E. Rockall (Naylor et al. 1999). The linked strands of this important lineament extend for at least 150km. The fault system creates the ancient Erris High and eastwards the dip-slope early Mesozoic Erris Basin.

The Erris Fault Zone also shows considerable geological longevity from Palaeozoic through Cenozoic time. There is evidence that substantial movement has occurred during the Paleogene/Neogene and most likely may have occurred as late as Mio/Pliocene times. The fault system is particularly high angle dipping at around 60 degrees or more and is often quite difficult to image and therefore map on conventional seismic data. It is suggested here that continued movement along the EFZ can be traced into the Recent.

The EFZ is predominantly made up of a 150km long lateral massif as a series of blocks, showing extensional movement down into the Rockall Basin to the west, **Figures 4a, 4b & 9**. There is also apparent secondary compressional or strike slip movement to the east of the ridge as well as offsetting that effects the foot wall block creating an often very narrow horst parallel to the main fault, **Figure 4a**, **DX 4** and **DX5**. Occasionally this back fault creates a low order scarp but this is dwarfed by the massive down to the basin feature, **Figures 9, 12 & 14** where the EFZ is shown coloured green or yellow.

The EFZ has had a profound influence upon structural and depositional development of the NE Rockall and this is still the case judging by the steeply dipping seabed and strong gradient features developed along its length at the present day seabed. These are observed directly from the bathymetry and gradient map, **Figures 5 & 6** as the elongate, NNE/SSW trending region of closely spaced contours between approximately 2.000 and 2.700 sec (1500m – 2025m) seen in the upper third quarter of the maps.

In more detail the EFZ is shown in light grey at 1:200,000 scale so as not to obscure other map details, **Figure 7.** The fault scarp associated with it is often 0.400 – 0.500 sec (300 – 375m) in height. This creates significant seabed gradient increases of up to 20 degrees and possibly more as shown on the 1:50,000 detailed map, **Figure 7a**. The individual fault strands (here in dashed light grey) and their linked offsets within the EFZ can clearly be seen by the seabed gradient changes shown in yellows and light reds in **Figure 7a** despite the obvious noise. These significant increases in what is already quite a steeply dipping continental slope are clearly seen to be the result of fault movements traceable on the seismic database right up to the present day seabed, Lines NWI-116 or NWI-115, **Figures 4a** and **4b.**

The next adjacent geoseismic profile Line DGER96-25 shows that the Erris Fault does not become an identifiable fault at seabed on every line. This is also noticeable from the **Figures 9, 12 & 14**. However, the association of the deep faulted structure with the increased slope of the seabed is strikingly clear. It would seem likely that it is only a matter of time before, as elsewhere along its length, the fault creeps up and through the thicker cover of Megasequence RT-a contourite sediments plastered onto the slope. Moving further to the south along the EFZ the lineament can clearly be seen to have faulted the sediments interpreted as Megasequence RT-b on Line NWI-91-112 and the fault activity is thought to be influencing the large, crested, wave shaped contourite sediment feature lying directly above it. This is also the case in the example shown as **Figure 9**. Here internal deformation or marked local change in depositional thickness (thinning) can be seen. This occurs directly above the noticeable Erris Fault lineament (green), which clearly offsets the C10 unconformity (blue horizon), upon which the climbing contourite sediments of RT-a are plastered.

Another major morphological feature apparently related to the EFZ is the development of the deeply incised slope valley/canyon systems that have been identified and mapped in the NE Rockall region. These are the Donegal Canyon, TOBI or 'T' Canyon and the DIAS or 'D' Canyon systems whose locations are marked on **Figure 3** and the location map of slope instability features map, **Figure 7**. The Donegal Canyon system occurs precisely where there is a noticeable major change in the trend of the otherwise NNE/SSW running EFZ. The major faults as interpreted at the BTU are offset back towards the shelf by some 1100m where they again take up a trend very similar to the regional.

Since seismic interpretation and mapping shows the location and movement along the EFZ appears directly responsible for the Donegal Canyon system it is likely this is the same for the ‘T’ and ‘D’ Canyon systems further south. Here the canyon/valley systems incised into the slope run virtually perpendicular across the EFZ and parallel the majority of the dip-orientated seismic dataset. Mapping of the EFZ by others (Norton pers. comm. and Naylor et al. 1999), shows a significant NW/SE trending offset moving the Erris footwall further west and into a more base of slope environment through Blocks 11/27 and 11/28. This is just where the ‘D’ Canyon system occurs and data deteriorates. Such observation has not been verified during this brief study – the SW/NE EFZ trend appears to continue as shown on Figure 27b of RSG Report 98/23, but the possibility strengthens the relationship between deep seated faulting and canyon/valley initiation and thus the commencement of slope destruction and resulting unstable conditions at the seabed. Further discussion of the canyon features as areas of increased risk to seabed stability follows below in **Sections 6.4 and 6.5.**

6.2. Low Angle Faulting Creating Seabed Morphology

The kind of faulting described in this section is completely different to the long-lived structuration along the major EFZ. Many seismic data show shallow dipping, slightly listric surfaces cutting Megasequences RT-d through RT-a, **Figures 4a**, **4b DX 1**, **4**, **5**, **6** or **9**. Apparent vertical reflection offsets are generally only in the order of a few tens of milliseconds but these are clearly visible. In **Figures 8**, **10**, **12**, or **17** the shallow faulting may be seen to be responsible for the generation of bathymetric lows ('scallops') associated with the fault hanging walls, discussed below. Fortunately there is often sufficient 2D seismic data to correlate and map the fault cuts and planes with some degree of confidence although admittedly the mapped trends are biased to running sub parallel with the seabottom slope and orthogonal to the 2D dip line direction, **Figure 7**.

Of considerable importance to this investigation is the observation that the fault planes are traceable up to the no data zone directly beneath the current seabed as resolved on the exploration 2D seismic data. Here there is a strong link between the N/S trend of the fault lineaments and well defined, hummocky bathymetric low trends occurring generally on the hanging walls of the faults. This is observable on the 1:50,000 scale map **Figure 7a**. The scallops and troughs are invariably on the downslope side and it seems certain the broad linear troughs must be the response of the seabed sediments to the instability caused by the underlying fault movement. The fault troughs are 50m or more deep although this is somewhat difficult to estimate precisely since it is likely that the updip slope of the troughs may be influenced to a certain extent by footwall uplift **Figures 10**, **12** & **17**.

Another major point to be considered is the relationship of the faulting and its seabed expression with the depositional and erosional processes applied by the forces of Atlantic Ocean water systems. Enhanced erosion along the hanging walls could be responsible for the observed bathymetric lows and this is indeed interpreted to be happening as is the concordant dumping of sediment as energy dissipates up and over the upstanding foot wall of the fault lineaments. Estimates of the rates at which either of the fundamental processes, (deposition/erosion by contourite currents or active structural movement), are operating and how these change along the slope requires far more investigation and mapping. What is clear is that both would appear to be acting in combination, fitting with evidence seen elsewhere in the Rockall Basin and further afield along the Atlantic Margin, of an overall dynamic depositional system where underlying tectonic influence is often subtle but fundamental, **Figures 9**, **12** & **14**.

The location map of slope instability features, **Figure 7**, shows that seabed faulting has been identified and mapped to extend as several important en echelon systems trending NE/SW traceable for at least 100km. Sporadic occurrences are also mapped elsewhere but have not developed (? yet) into fault elements mappable for more than a few lines (5-10km) given the present data grid and interpretation.

As shown in **Figure 4b**, the younger Tertiary sequences show a relatively high frequency of faulting. Observation shows that not all the fault planes actually cut right up through to the seabed although many do. The appearance is, however, that the system is actively "growing" in the sense that the more updip faults closer to the upper slope environment do cut and it is perhaps only a matter of time before the more downslope faults also penetrate up to the seabed. Active sedimentation or erosion rate and the strong influence upon this by current activity is also involved and the evidence is, (from Logachev Cruises further south) that current activity is intense in the upper slope and outer shelf environment where strong mixing occurs due to the rapid changes in water depth on the oceanic water masses. Indeed the interpretation is occasionally of similarly shaped concavities associated with non seabed-cutting faults that were probably once exposed at seabed. They have since been smothered by sedimentation, (either as up and along slope contourites or by downslope mass wasting processes), that is inferred to be ever-present but which unfortunately cannot be well imaged given the resolution of the current database. **Figures 9 – 14**.

6.3 Borehole 11/20 Slide and the V-shaped Canyon

The ever-present force of gravity as it affects smaller scale mass wasting and down slope movement processes is considered as fundamental to the investigation of slope instability as the faulting described above. It seems logical to suppose it is the influence of day-to-day, year-to-year and 50, 100 or 1000-year storm occurrences that act in combination with faulting to help modify the slope by the mass movement of material downslope. This section identifies and briefly documents an area of NE

Rockall that appears to show clearly this interaction although much further work is necessary to fully unravel the picture completely.

Figure 16 shows a large, cuspate seabed scarp and part of the massive seabed slide feature discovered during the TRIM study. It is here termed the BH11/20 Slide after the shallow drilling site / borehole near its SW edge, **Figure 7**. This feature has been interpreted with the benefit of integrating the TRIM work, the exploration 2D seismic data, some limited higher resolution data recorded by BGS plus the limited borehole data, mapping by UCD (Praeg & Shannon 2000) and the single result of a sedimentological study of ten gravity core samples.

The BH11/20 Slide feature has been identified and mapped to occur over some 200 square kms of the seabed updip of the EFZ and terminating close to the hanging wall of the shallow listric fault lineaments cutting the upper slope as described in **Section 6.2** above. At the 1: 200,000 map scale of **Figure 7,** the slide footprint is surprisingly near recto-linear in plan (due to the wide 2D grid spacing), although several cuspate edges and a better defined channel or dendritic shape is seen to characterise the more proximal NE corner where the closer spaced and more resolute data exist. From **Figure 7** the association of the BH11/20 Slide with both the footwall of the EFZ scarp, the several shallow fault lineaments up slope of this and also the shallowest linear fault system at 0.600-0.700sec water depth is clear. From the seismic interpretation a further structural and rheological influence also exists in this region - that of the differential compaction differences between late RT-d to RT-a aged sediments and the underlying Lower Paleogene (earlier RT-d) sub aqueous volcanic cone. The well defined sidewall seabed scarp feature marking the SW limit of the BH11/20 Slide is strongly influenced by topography of the now partially exhumed volcanic surface that is probably of RT-d age.

A direct linkage between the seabed slide feature with it's local highly cuspate 'slide scar' lateral structure with the more regional faulting, as mapped so far, remains unclear and somewhat speculative but is surely crucial enough to warrant an investigation in its own right. It does seem clear for example that the sporadic, discontinuous slope parallel faulting running through the middle of the slide feature (SP 845 on line NWI-91-116, **Figure 17**, has influenced the formation of the main back wall scarp of the slide at that location. As shown on the map and in **Figure 16**, however, the SW limits of the slide can be mapped the run directly *down* rather than along the slope like the structural, shallow faulting trend thus creating the well imaged scarp feature. The SW/NE (strike) portion of **Figure 17** shows the slope failure scarp, which is 140m high, truncating the sub parallel reflections at SP 2350 – 2380 with the failed sediment mass interpreted in green. The obvious depression at the foot of the scarp is interpreted to be a scour or moat-like feature. It is formed as a classic response by the oceanic current systems active on the slope to the assumed sudden change in bathymetry as the slide moved catastrophically downslope. This would presumably have occurred following movement along the back wall faults that in turn die out within the underlying volcanics.

The three annotated, dip orientated high resolution seismic profiles in **Figures 18 – 21** try to show the massive slope failure feature in context to the few sample points that barely scratch it's surface. The samples were taken to meet different objectives and lie close to intersection points of the higher resolution seismic grid. They unfortunately were not targeted specifically at the slide feature or its scarp nor associated faulting. Few surficial samples from BH11/20 itself were recovered, **Figure 18**. The Megasequence RT-a Pliocene clays and gravels as described to date could represent either the intact footwall or the slide sediments themselves. Perhaps they can be correlated as being so similar to some of the more definitely slide located gravity cores as to answer this question and hence provide a primary, albeit circumstantial datum point for the slide feature.

The **Figures 18-21** also show the interpreted stratigraphy and structure as correlated from the surrounding regional and basin- wide analysis. The **inset** on **Figure 19** of Line PH99GP0135A shows the next available exploration seismic line parallel to dip Line NWI-91-116 of **Figure 17**. Note the volcanic cone is now much reduced and the central, shallow, down to the basin faulting acting as the back wall for the BH11/20 Slide (green) is consequently not as evident.

Figure 22 shows the log of the single gravity core sample (SC001) available for this investigation and **Figure 18** shows how it is located on a local high within the BH11/20 Slide feature. The local high is not thought to be the noticeable inter-slide high that can be seen at SP 2500 on Line PH98GP0110B around which the slide sediments appear to have flowed. Taking a broader view there are several other small scale highs within the BH11/20 Slide that require further explanation given their locations adjacent to deeper canyon/valley systems.

The relationship of the slide feature to the upper slope fault system should be more closely investigated since it seems logical that the initiation mechanism for the major lateral, downslope mass movement system could have been *triggered* by the more vertical movements associated with the fault mechanism. Working in combination with Gravity, the build-up or changes in sediment pore pressure are thought to generate *small-scale* debris flows and mini slides on the seafloor. Over time these relatively tiny downslope mass movements grow and in turn create conditions possibly likely to lead to a more catastrophic, larger mass movement – given the positive alignment of all the other factors and/or the addition of an *instability catalyst action* to initiate the larger scale movement. It could be that the balance may be tipped by either one of the following or a combination of them: -

1) weak earth tremors, (known to occur over offshore regions previously considered aseismic);
2) sediment pore water pressure increases perhaps driven by long term periodic processes such as may be generated under severe atmospheric low pressure storm conditions or oceanic water layer boundary instability;
3) Critical angle –like influence from rapid sedimentary deposition;
4) Increase or injection into the pore fluid system of clathrate methane or higher end gases migrating up the linked fault system

The small-scale flows and movement eventually build up into larger slide deposits that may then fail more en masse as 'intact failures' under particularly large or exceptional conditions over time. These processes are thought to provide the kind of geometries, flow patterns and seismic stratigraphic features observed in NE Rockall. They are similar to those identified elsewhere during the study and research of other medium or very large mass movement features along the N.E. Atlantic margin e.g. Suduroy Basin, Austin 2001, Storegga Slide, pers. comm. BP, Meinhart, 2001 in Press.

Not only does **Figure 21** display a good cross sectional view across the BH11/20 Slide, the profile also shows the huge slide feature is actually dwarfed by the presence of an incisive, V-shaped canyon/ valley system. The system is 3.5km wide at this point and its steep sides cut down three-quarters of a kilometre into the seabed of the slope where it appears, at this point, to be flushed clean of any collected sediment.

The development of this canyon/valley system, which seems quite unique within the area of investigation, is shown in profile in **Figure 23.** Movement along the EFZ may have initiated it since it is located close to a back-to-the shelf offset of the fault,

Figure 7. This is complicated, however, by the fact that the canyon system is noticeably perched above the Donegal system by almost a kilometre – showing the V-shaped canyon to apparently be on the footwall of the fault. The cauliform canyon system to the NE is not well understood from the current dataset, **Figure 38** but does appear to represent the higher reaches of the V-shaped canyon in that area. Here in it's upslope environment the system becomes difficult to differentiate from the BH/11-20 Slide whereas downslope the canyon system is surprisingly narrower but is still seen to be cutting through the slide. Another surprising fact is that although where **Figure 21** crosses it the V-shaped canyon is empty of sediment, further downslope it becomes sediment filled. The feature does, however, still remain as a definite v-shaped incision into the seabed before it disappears apparently beneath the interfingering basinal fill near the base of the slope.

Future effort in unravelling the canyon system and the sedimentological and stratigraphic clues it could be hiding seems warranted since an important deduction of relative event timing from the features indicating slope instability could be made as follows.

The presence of the V-shaped canyon cross-cutting the slide, **Figures 21 & 23**, gives us our first fairly confident seismic stratigraphic relationship in attempts to unravel the relative timings of the features indicating slope instability in the N.E. Rockall region.

Simply, if the faulting initiated the slide then the V-shaped canyon must be relatively younger than the faulting as well as being obviously younger than the slide deposits it cuts through. This deduction suggests that the feature is likely to be late Pleistocene - Recent since the faulting must be of at least late Pleistocene - Holocene age because it cuts up to seabed. Should such a young age be correct this might have a bearing on why the canyon system contains very little sediment fill along much of its length until the lower slope environment. It is recognised that there still remain several important questions and corollaries necessarily to be considered from the above ideas, which is why further investment in specialist study concentrated on this particular feature and area would add value to the present investigation.

Given the differing nature of the V-shaped canyon system along its length is it also possible - as an alternative idea – that the canyon system existed as an erosive feature in the slope *before* initiation of the slide? Perhaps there was initially an existing canyon /valley system which then became modified and more sharply eroded due to the failure of the BH11/20 Slide. Perhaps the valley flanks and base were sculpted by the basal processes acting upon it as the slide sediment flows passed by on their way downslope to continue the deposition of the lower reaches of the canyon. Delineation of the slide becomes progressively more difficult approaching and especially downslope of the Erris Fault Zone scarp making every idea on the links between the seabed features more or less conjectural until further work is allowed.

Much of the reasoning above adds significant strength to the assessment of instability of the present day seabed slope. It would appear to put the risk into the relatively high category. The implications of this conclusion have immense ramifications to the industry. It should not be forgotten, however, that the database is far from optimum and that:

1) The deductions are from seismic correlations based upon exploration seismic and sparse geological data points many tens and hundreds of kilometres apart.

2) Crucially there are no useful C_{14} AMS age dated samples of the seabed sediments currently exposed to confirm the assumed latest Neogene age.

3) This leaves the deductions and far reaching conclusions drawn from them open to the argument that the present day seabed could in fact be a *relict seabed* – a feature of the late Pleistocene that has been preserved virtually intact or perhaps was previously buried and has now become exhumed, for example, by oceanic circulation current activity.

If the deductions are, however, correct then further geological study is warranted to fully document and extend the arguments further than can be dealt with here. This would lead hopefully towards a more predictive assessment of risk to instability of the seabed in the NE Rockall region and elsewhere thus maximising value.

6.4 Donegal Canyon System

The Donegal Canyon System is located in the NE corner of **Figure 7**. The canyon/valley system starts as a huge, 20km long, steep head wall slope at the 375m, (0.500 sec) water depth contour. It runs towards the NW for at least 40km to reach the Rockall basin environment at 2,250m (3.000 sec). Geoseismic profile Line WM90-391, (DX3), on **Figure 4a** provides a good overview and illustration of the valley thalweg of this enormous and important geological feature. The upper reaches are formed of steep sided canyons that are more rounded or cauliform in the NE, (around the 12/13-1A well location), compared to those closer to the V-shaped canyon where again there is a moderately straight head / side wall feature developed, **Figures 23, 23a**. The reason for the straight borders to the canyon/valley system is thought to be due to the underlying presence of the EFZ, one branch of which clearly trends WNW/ESE very close to the southern Donegal canyon margin, **Figure 7**. Faulting is also likely to be responsible for some of the straighter NE flanks and the more cauliform features, in time, may well be eaten back to fully reflect the shape of the apparent underlying rhomboid fault geometry in this vicinity.

Located on **Figure 26,** the **Figures 27 & 27a** show profiles across the Donegal Canyon/valley system that suggest a basal fault on *upslope* Line 183 may be responsible for the collapse and down slope movement of the estimated 5-600 cubic kilometres of seabed. The (orange) fault can be correlated on line PH118 to PH114, however cross cutting faulting as per PH116 or PH112 is also observed. On Line PH112 a further basal fault in green can be seen, as on *downslope* Line PH108 where it creates the NE boundary of the canyon system. Further work is required to unravel, correlate and more completely map the inferred faulting, (seen clearly on some seismic lines of the available data grid), to prove the fault movement mechanism of canyon development that is inferred here.

Evidence as to the age of the faulting *initiating* the Donegal Canyon system is not clear but it is probably early Palaeogene since, as is also the case for some other canyons along the Rockall margin, the Donegal Canyon is apparently associated with older faulting and cuts into the BTU, **Figures 29 – 32** (yellow faults). It does appear, however, that the latest stages of movement and possibly the currently active canyon generation mechanism in general, have strong late Neogene or even younger components. This is because observation of the canyon systems often shows that they appear to have a composite history. This is judged by the complicated stratigraphic history indicated by the box-like, broad U-shaped, V-shaped or other external profiles together with the reflection geometries of their sedimentary fill exemplified by the **Figures 28 – 33**. There appears to be some evidence for at least two major stages of valley cut and then fill, followed by further cut and further fill.

Interestingly this hypothesis suits some of the canyon valley systems observed on some industry seismic along other Atlantic margins for example offshore W. Africa. Here sometimes the composite nature is so intense and at such a scale that former interfluval highs have themselves been scoured out and the former cut valley fill (channelised, cross-bedded - meander belt,) actually represents the present day bathymetrically ‘interfluval’ higher ground between the modern incised canyon/valley axes.

The precise dynamic sedimentological, climatic, oceanic and sea level fluctuations involved to develop such sequences remain to be researched with the advantage of necessary age dated sediment samples. It is important to recognise that globally similar processes may be involved in the formation and maintenance of the Donegal Canyon system and others in the NE Rockall region, Section 6.5 below.

Figure 28 for example shows low angle basal faulting that not only cuts the folded C10 surface but also cuts the younger intra RT-a aged C5 event. A layer of sub-parallel to parallel, occasionally mounded sediments covers both the canyon flanks as well as the axial troughs. **Figure 29** shows steeper flanks with sidewall faulting. External mounded reflection geometries infer large-scale contourite waveforms deposited in intra canyon areas. This phenomenon is seen as a characteristic of many canyon/valley systems developed down the whole length of the E. Rockall margin, Austin 2001c. Older channel troughs of RT-c aged sediments have been infilled e.g. between SP 1350 –1550 and new ones excavated into post C10-aged sediments complicating the seismic stratigraphic relationships which can be inferred from the interpretation along any particular profile line.

Similarly on **Figure 30** clear sidewall faulting is again well developed. It appears to be recent since the lower angle fault planes sometimes cut to the seabed e.g. at SP 1590, Line PH98GP0116 or else show apparently active associated seabed modification into mounds or wave-like features. **Figure 31** also shows the young age of the faulting particularly well where the Donegal Canyon System is mapped as being 21km wide at around 700 - 1000m water depth.

As water depths increase the canyon system shows more evidence for its composite history where thick lenses or mounded wedges of deformed and partially deformed sediment are interpreted to lie within the canyon system. These may indicate older hanging wall sedimentary accumulations since they appear to be of RT-b and RT-c age, **Figures 32 & 33**. This region of gross hummocky seabed and sub-seabed remains intriguing and poorly understood where little can be stated with certainty. If nothing else, the deposits such as the massive Gullwing Erris toe of slope wedge, add to the evidence of long and continued history of movement along the EFZ and its associated fault lineaments as suggested in Section 6.1.

6.5 'D' and 'T' Canyon Systems

Figure 34 regionally relates the features described above in Section 6.4 to the 'D' and 'T' Canyon region in the south of the area of investigation in N.E. Rockall. It is clear that structurally the area is quite complicated at depth with several faults affecting both the pre and post-BTU section. Slope sidewall faulting is also present as is evidence for several periods of canyon/valley system sedimentary fill.

Geoseismic Profile Line NW193-106 on **Figure 4b** provides a good impression of the massive indentation cut into the seabed slope by the 'D' Canyon System before it swings towards the NW around and then through the Gullwing Erris toe of slope wedge deposits, **Figure 7**. As with the Donegal Canyon System, the impression is of a composite cut and fill system since the RT- b aged wedge is eroded and then covered with Megasequence RT-a sediment that partially fills the sculpted canyon floor.

The 'D' and 'T' Canyon /valley System features cover a large southern portion of the map, some 75 km wide, **Figure 7** and although there are similarities, the features also show differences to the Donegal Canyon System 100km to the north. The 'D' Canyon System consists of four major steep sided and deep canyon/valley axes which meander significantly in their journey from the outer shelf/upper slope down to the lower slope/basinal environment. Here the last and most southerly incision of the 'D' system coalesces with the more major valley in which the three upstream branches have linked higher up slope.

The upper reaches of the main 'D' system are quite sinuous with noticeable near slope-parallel orientations for the canyon/valley floor axes. These have been mapped directly from the seismic grid as far as possible independently. They mostly tie very well with the actual canyon/valley footprints as shown on the TOBI interpretation maps. Where any location discrepancy occurs it is almost always in the identification of the valley floor – slope gradient change and the seismic location for this has been adopted on **Figure 7**.

In contrast with the 'D' system, the 'T' Canyon/valley System tends to take a far straighter line to cut through the slope down to the base level of the Rockall Basin Floor. Indeed, as is noticeable from the regional bathymetry, **Figure 5,** two present day canyon axes run in parallel to cut virtually directly NW/SE from outer shelf to Basin Floor. This leaves an almost ridge–like seabed feature over 300 metres high that is captured in profile on **Figure 35**, SP250-300 on Line ST9505-209 and 1500m SE from this location at 23:30hrs on the corresponding TOBI 3.5kHz pinger data.

Of considerable interest is the imaging on several seismic lines as well as the pinger of two separate diffraction centres at either side of the straight, interfluval ridge. These are interpreted as possible waveform crests. Unfortunately no seismic data clearly images the suspected internal reflection geometry of the ridge but it is strongly interpreted as being of either contourite or chanellised origin. This could imply that the interfluval ridge it is actually an earlier depositional feature, which has been uncovered and eroded by the most recent present day cycle of the 'T' Canyon/valley System. This in turn implies the canyon/valley system is longer lived and perhaps far longer lived than its simple interpretation just as a present day seabed feature would suggest. There is a strikingly similar comparison here with the W. African examples of complex canyon development as described above in Section 6.4.

The role of contourite current activity in the formation, (presumably after catastrophic initiation or further increased development) of a pre-existing canyon/valley system is considered here to be very important in the history and evolution of both the 'T' and 'D' Canyon systems. The detail of **Figure 36** shows in profile the typical seismic complexity across part of an active channel system within the 'D' Canyon. The figure is located 2-3km SE of where the two 'D' canyon axes coalesce at around 3.100sec on **Figure 7**. Here two axial systems are separated by 5 – 6 km and the more southwesterly (right-hand) shows a 150m difference in height above the left-hand (northeastern) channel axis. Both have a similarly v-shaped profile with depth and show a well-defined flat valley floor some 4km wide indented by presumed meander cut channels and depositional bars or levee-like lobes of a few hundred metres in width.

Just this type of depositional characteristic has been confidently imaged on a single, proprietary 2D seismic line further south outside this area of investigation as a classic channel-levee system. This is further supported by the fairly well imaged gross reflection geometries of the seismic packages comprising the canyon/valley axial fill. Internal reflection geometry patterns range from sub-parallel to parallel and well layered (levee), through to chanellised, opaque, diffractive and chaotic which no doubt reflect the channelled facies and also the spoil from sidewall slumping and collapse where imaged.

Between SP 1820 and 1860 on **Figure 36**, two distinctive and here, contourite waveforms are interpreted that lie broadly at the edge of the chanellised valley floor fill separating one channel from the other. These waveforms have a maximum height of 70 metres and width of 1000m. They have been identified and correlated on seismic as well as the TOBI sonar data interpretation to extend for at least 25 km up the canyon/valley system. Their age and direct association with either the channel fill sediments or possibly the deeper, strangely transparent older channel fill, together with the evolution of canyon/valley systems through time, requires much fuller investigation and analysis than can be described here.

Another observation from **Figure 36** is that the relative 150m height difference of the current channel floors is virtually the same at depth within the channel system where a more prominent and stronger amplitude base channel surface might be interpreted at 3.100 sec, (red between SP 2000 –2200), **Figure 36**. Deeper-seated faulting (yellow) appears to tip off near this surface, which is very difficult to correlate line to line in this area. The surface is, however, interpreted as the deformed and undulatory upper part of the Gullwing Erris Toe of Slope Wedge (GE Wedge) sediments – thought to be a regional remnant of earlier catastrophic mass movement of the slope. The canyon/valley system has developed its often convoluted pathway over, into and through this major barrier to reach the base level of the Basin Floor.

Returning to the gross morphology of the 'T' Canyon System the most northerly axial branch (NE 'T' Canyon System) is decidedly less straight and more cauliform than the more southerly pair at depths shallower than 2.500sec. Again the canyon/valley heads are often associated with fault lineaments that cut up to the present day seabed described in **Section 6.2.** Here the canyon/valleys do not cut further back into the shelf itself although just to the south the adjacent straight canyon shown on **Figure 7** does cut impressively all the way through to the shelf break at 0.600sec, (450m).

A further fact linking the development of slope canyon valley systems with risk to instability of the slope is the identification and location of a further seabed slide feature - the 'T' Slide, which appears to be perched upon the north slope of the mid – upper reaches of the NE 'T' Canyon System, **Figure 7**. The seabed slide feature is identifiable on TOBI and one or two 2D seismic lines, **Figure 14**. The 'T' Slide is quite narrow (4km max) and short being only around 8km from head to toe.

Again as with the BH11/20 Slide, the direct physical and timing relationships of seabed slope slide features such as this and the links to the evolution of canyon valley systems in general, require further study and research. In **Figure 14** for example there is strong evidence of the presence of active contourite moats and wave features. Furthermore the apparent similarities in reflection character of the uppermost 70m of sediment forming both the 'T' Slide and the axial fill of the 'T' Canyon System itself need to be reconciled.

At least four cycles of axial fill can be interpreted above the green reflector almost comparable with some of the late Quaternary – Holocene infilled channels in the N. Sea. At this early stage of research these sediment could also be interpreted as being synchronous with the up-slope aggrading contourite sediments observed beneath the 'T' Slide. If this were the case it would infer that the canyon/valley systems have been filled only with contourite and/or slide material. This may be quite likely the case but does not aid us sufficiently in trying to identify the likely stratigraphic history, which is a pre-requisite for confident risk analysis as to instability of the slope.

7. CONCLUSIONS

Generally the late Paleogene – Neogene - Recent history of NE Rockall is one of deposition from shallower water, slope prograding systems mixed with powerful deeper water systems depositing contourite sediments during RT-a to Recent times. A strong interplay has existed between the two contrasting systems with contourite-like sedimentation approaching the upper slope /outer shelf environments as well as in the more usual setting of the much deeper slope environment.

Contrasting with and superimposed upon these depositional systems has been a long history of active slope erosion and destruction notably by: -

1) Reactivated deep-seated fault movement.
2) Shallower faulting of apparently Neogene to Recent age.
3) Evolution of slope canyon / valley system development.
4) The same deepwater current systems responsible for the deposition of contourite sediments, which may also be involved in development of 3) above.

This interplay has been acting upon a slope that is generally very steep due to the late Cretaceous / early Tertiary earth movements as part of the development of the Rockall Basin itself.

Perhaps to a certain extent the late Paleogene and Neogene age and composition of the sediments makes them susceptible to erosion by bottom current activity. The high degree of destruction of the slope into its present day configuration of strongly dipping scarps, steep slopes and quite sharp gradient changes appears, however, to owe itself fundamentally more to the structural environment of down to the basin faulting. The faults are linked to the pre Tertiary structural history in some but not in all cases. Many examples exist of faulting dissipating within Megasequence RT-d whereas relatively few can be confidently traced through the BTU. The major exception is the Erris Fault Zone, which does show continued and major movement throughout the Tertiary until the present.

The numerous large, downslope mass movement features such as the BH11/20 or the 'T' Slide observed in NE Rockall provide both destructive as well as depositional elements. They are additional to all the above elements and provide further evidence to the unstable history of the NE Rockall seabed and slope. Depending upon the critical assumptions made that the present day seabed is not a relict feature, the results of this investigation strongly suggest that the slide material has moved during the geologically very recent past. This fits with observations made along the Faroese and NW UK margins where age dating constraints show large scale seabed instability to have occurred well within the last 10,000 if not 5,000 years or less. More specifically targeted high resolution data and consequent seabed sampling with age dating is necessary to hone down the seismic stratigraphic evidence to point towards conclusions that affect an acceptable engineering time scale such as field or pipeline lifespan.

The canyon /valley systems within NE Rockall are complex and composite features with evolutionary history extending back perhaps to the end Cretaceous / early Paleocene. The evolution of the Donegal Canyon System appears strongly linked to spatial offsets in the Erris Fault Zone. In development through time it shows the influence of contourite systems both scouring and redepositing sediments as well as effects by other possible faulting components. The under-explored V-shaped canyon system and its relationship with the BH/11-20 Slide and active, slope parallel seabed faulting area are further candidates deserving fuller attention and focus than could be given justice to here.

Likewise the 'D' and 'T' Canyon Systems show an evolution through time and although apparently not directly related to the EFZ, their headwalls do commence in the upper slope/ outer shelf environment where shallow listric faults cut up to the current day seabed. Strong association with oceanic current activity covering the range of conditions from erosion and scouring-clean, through to full deposition are evident from this investigation. By mapping of the interpreted wave forms it can be concluded that current patterns exist, or have existed in the past, that run virtually perpendicular to the slope down the straighter branches of the 'T' Canyon System. Further investigation is required to link these observations with those made in shallower outer shelf waters to the south, (Logachev coral mounds area). Here there is evidence for water movements to be more parallel to the shelf/upper slope. The possibility of major ocean system 'oscillatory gyres' acting to reinforce older pre-existing canyon systems throughout the Tertiary may be a reasonable supposition to help explain the destructive and unstable nature of N.E. Rockall.

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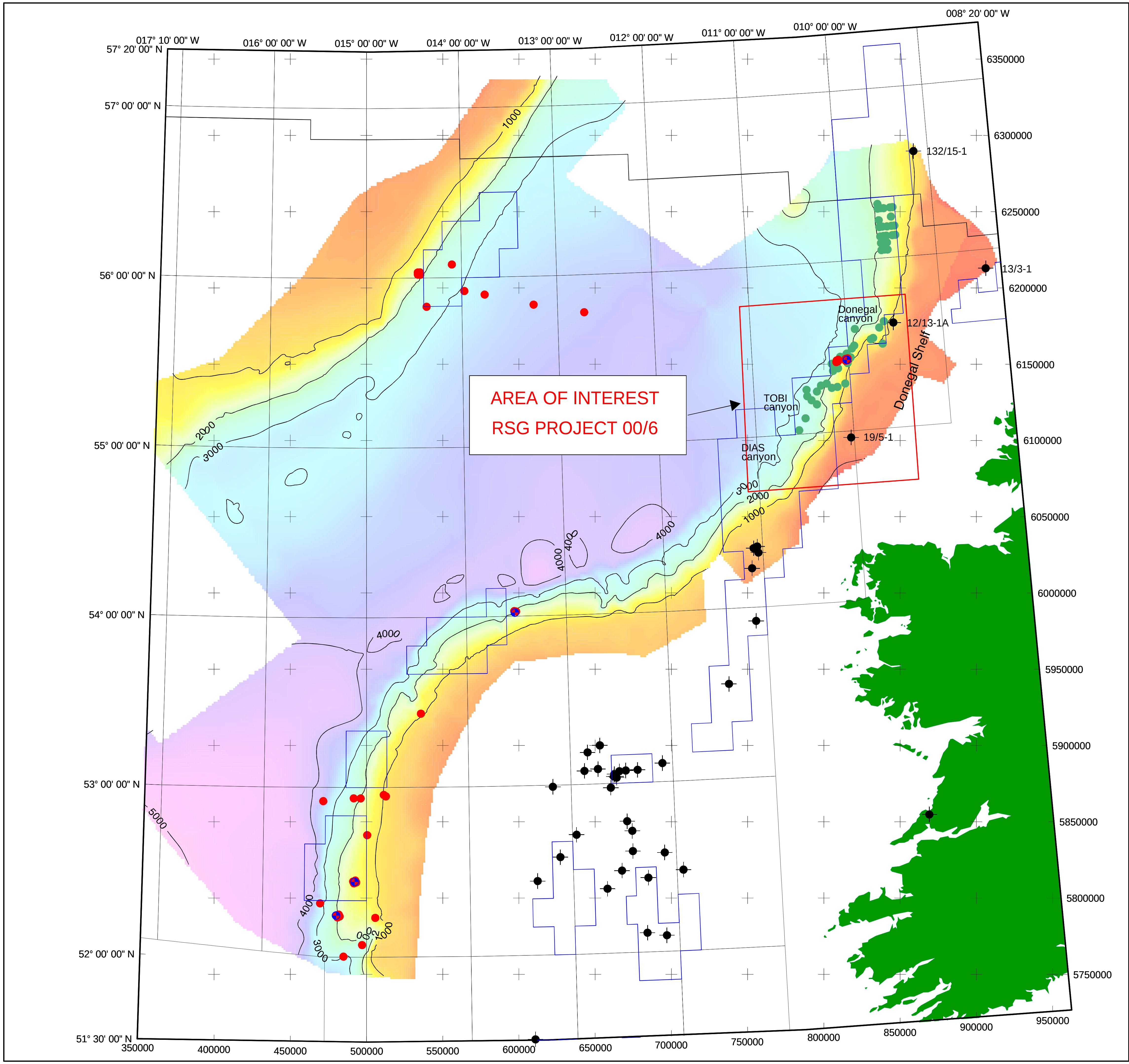
Figures



Petroleum Infrastructure Programme
Rockall Studies Group

HYDROSEARCH

Legend

- Wells
- BGS Gravity Cores
- Shallow drilling locations
- Geoboy cores
- Seabed Slope Project Area of Investigation

NOTES

Cell Size = 500m

1:2500000

0 20 40 60 80 100

KILOMETRES

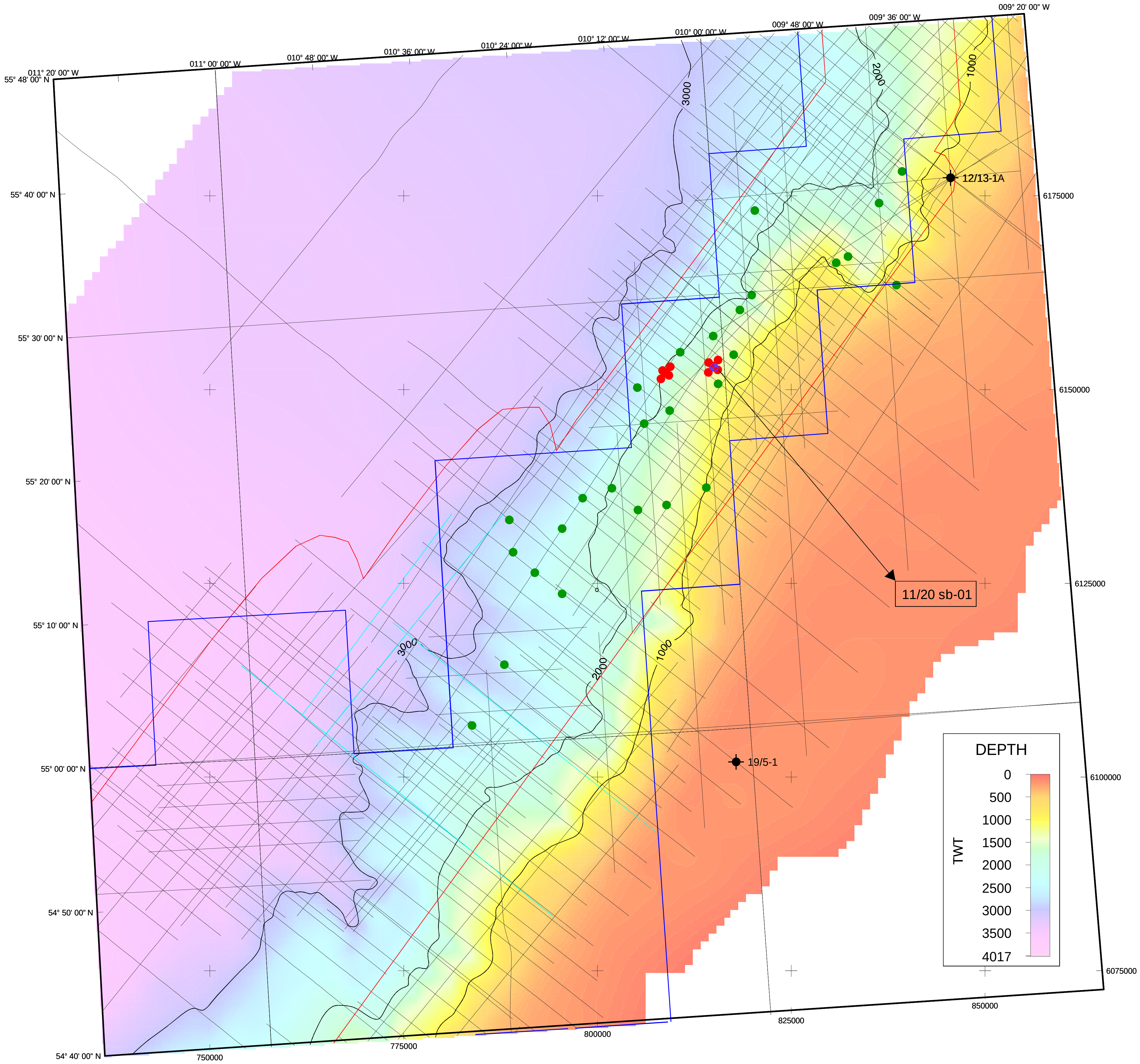
Universal Transverse Mercator Projection, Zone 28 N
International 1924 Spheroid
Central Meridian 15 W
Map Sheet Datum: ED50 Common Offshore

Hydrosearch Associates Ltd

Figure 1

LOCATION MAP

Author: BJA CW NSW	Date: May 20 2002
RSG Project 00/6	Revision: Final BJA



Petroleum Infrastructure Programme

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HYDROSEARCH

Legend

- Wells
- BGS Gravity cores
- Shallow drilling location
- Geoboy Cores
- Seismic lines
- NIOZ 2000 seismic lines
- TRIM Coverage

NOTES

Grid cell size = 500m

Challenger (BGS) Hi Res Seismic (not shown), covers area of BGS gravity cores around 11/20 shallow drilling site.

1:500000

0 8 16 24 32 40

KILOMETRES

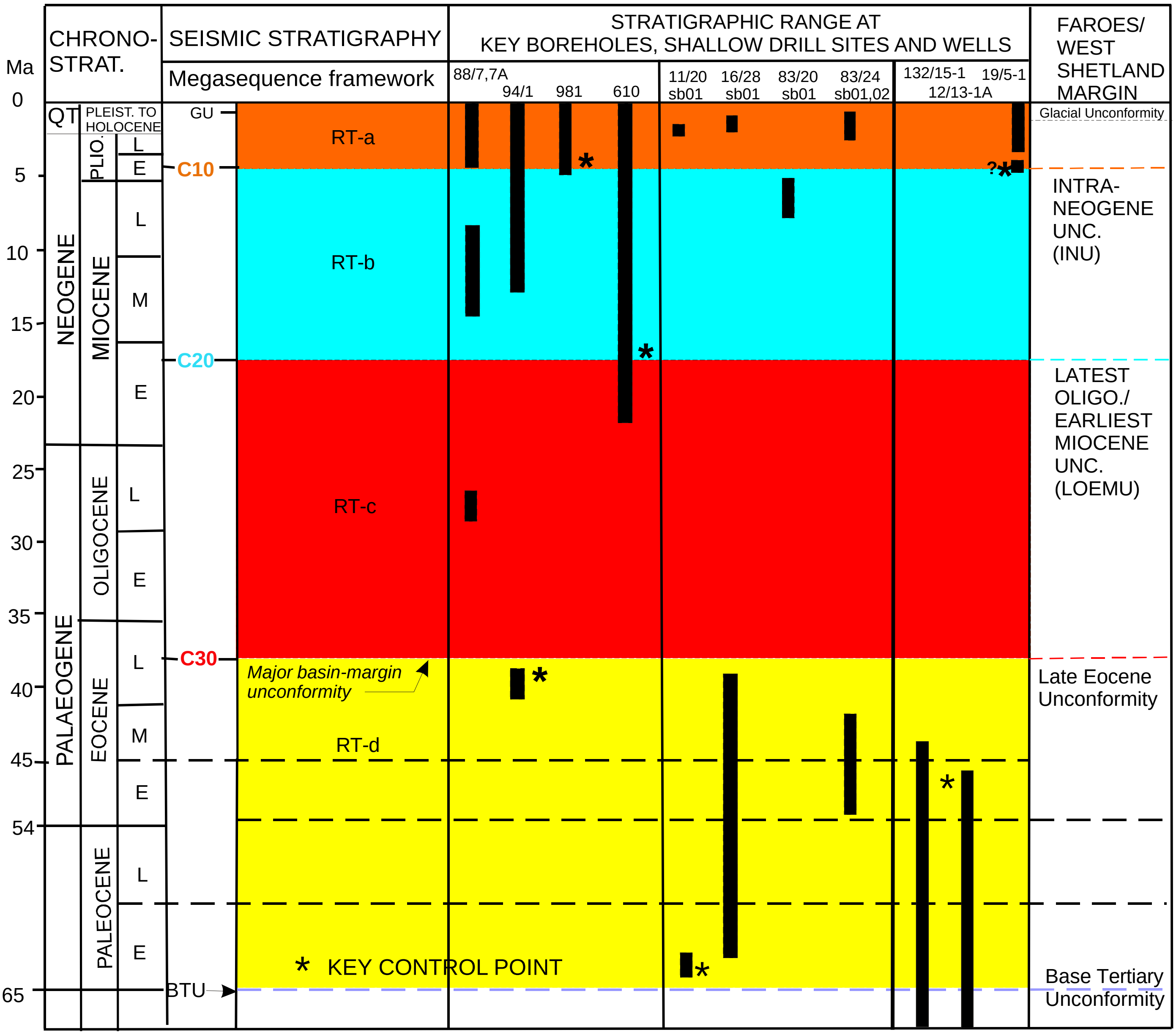
Universal Transverse Mercator Projection, Zone 28 N
International 1924 Spheroid
Central Meridian 15 W
Map Sheet Datum: ED50 Common Offshore

Hydrosearch Associates Ltd

Figure 2

DATABASE MAP

Author: BJA CW NSW	Date: May 20, 2002
RSG Project 00/6	Revision: Final BJA



After Stoker et al, 2001

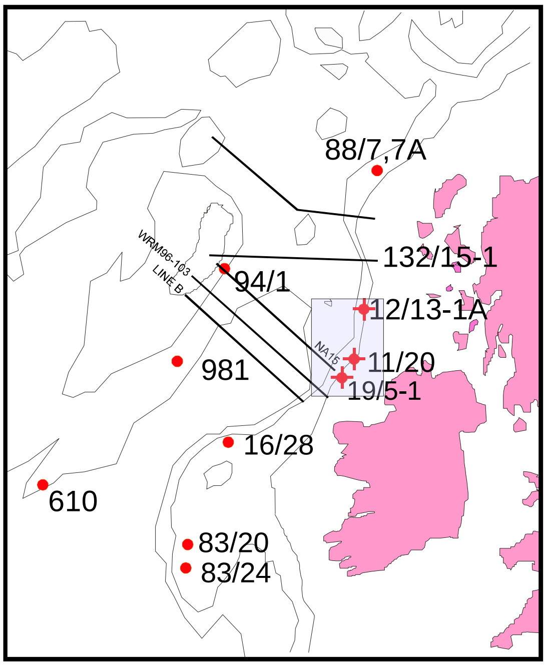


Figure 3

Seismic stratigraphy and stratigraphical age range chart of key borehole and well data used to establish the Stratigraphic Framework interpreted in this study region (highlighted area).

Figure 4(a)

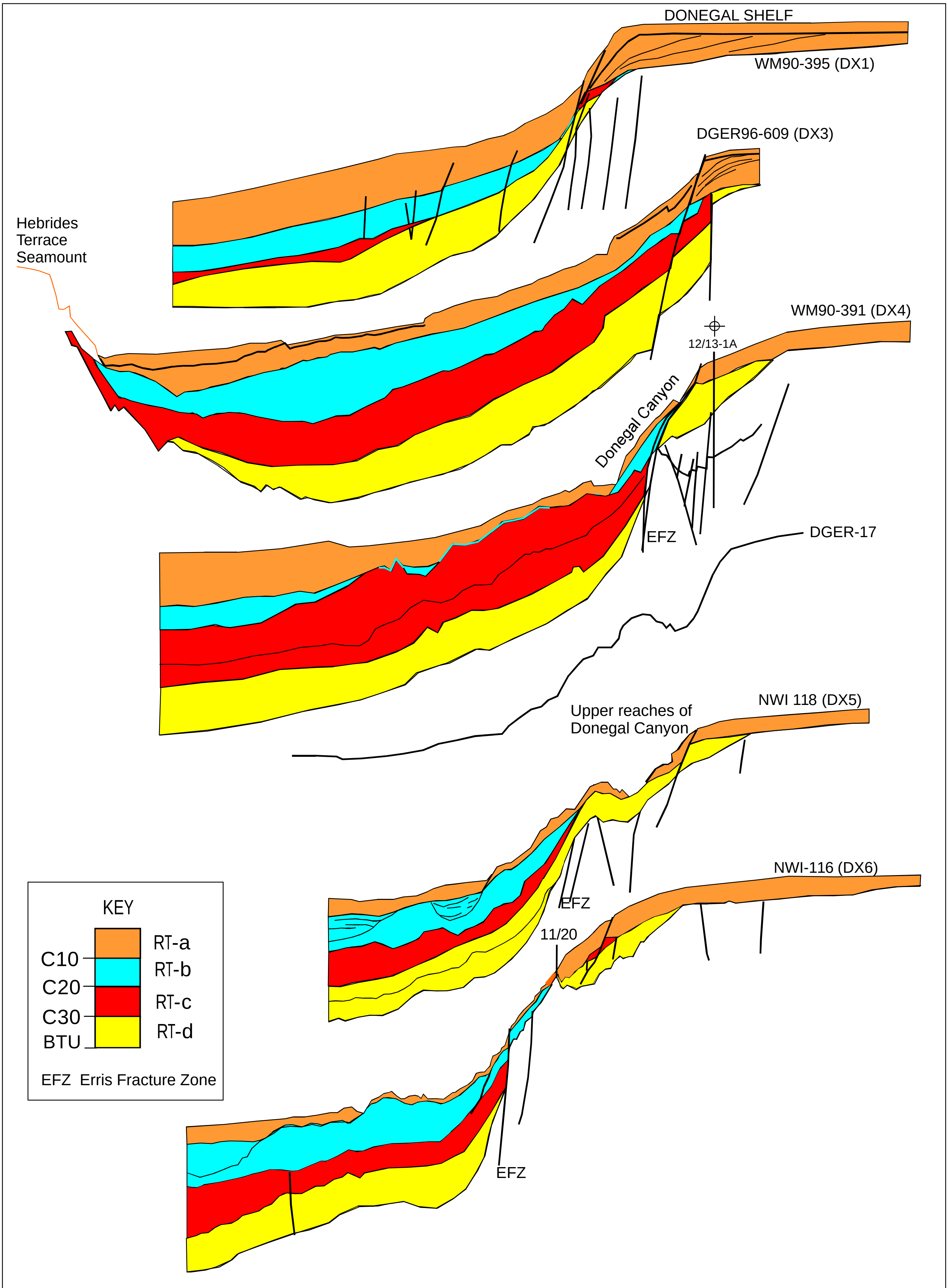


Figure 4(a) Bathymetric and Geoseismic Profiles - NE Rockall - for location see Figure 4(c)

Figure 4(b)

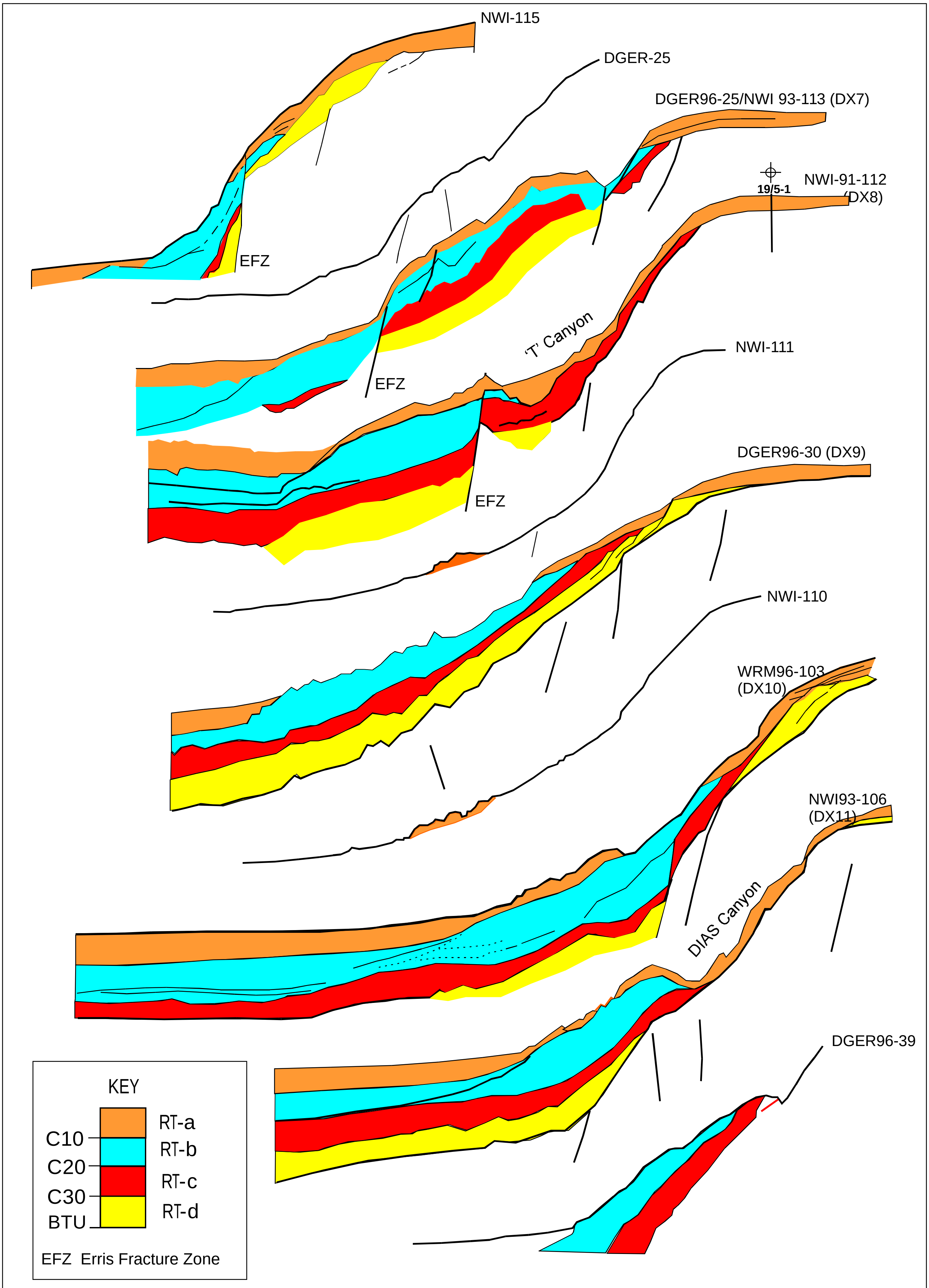


Figure 4(b) Bathymetric and Geoseismic Profiles - NE Rockall - for location see Figure 4(c)

Figure 4(c)

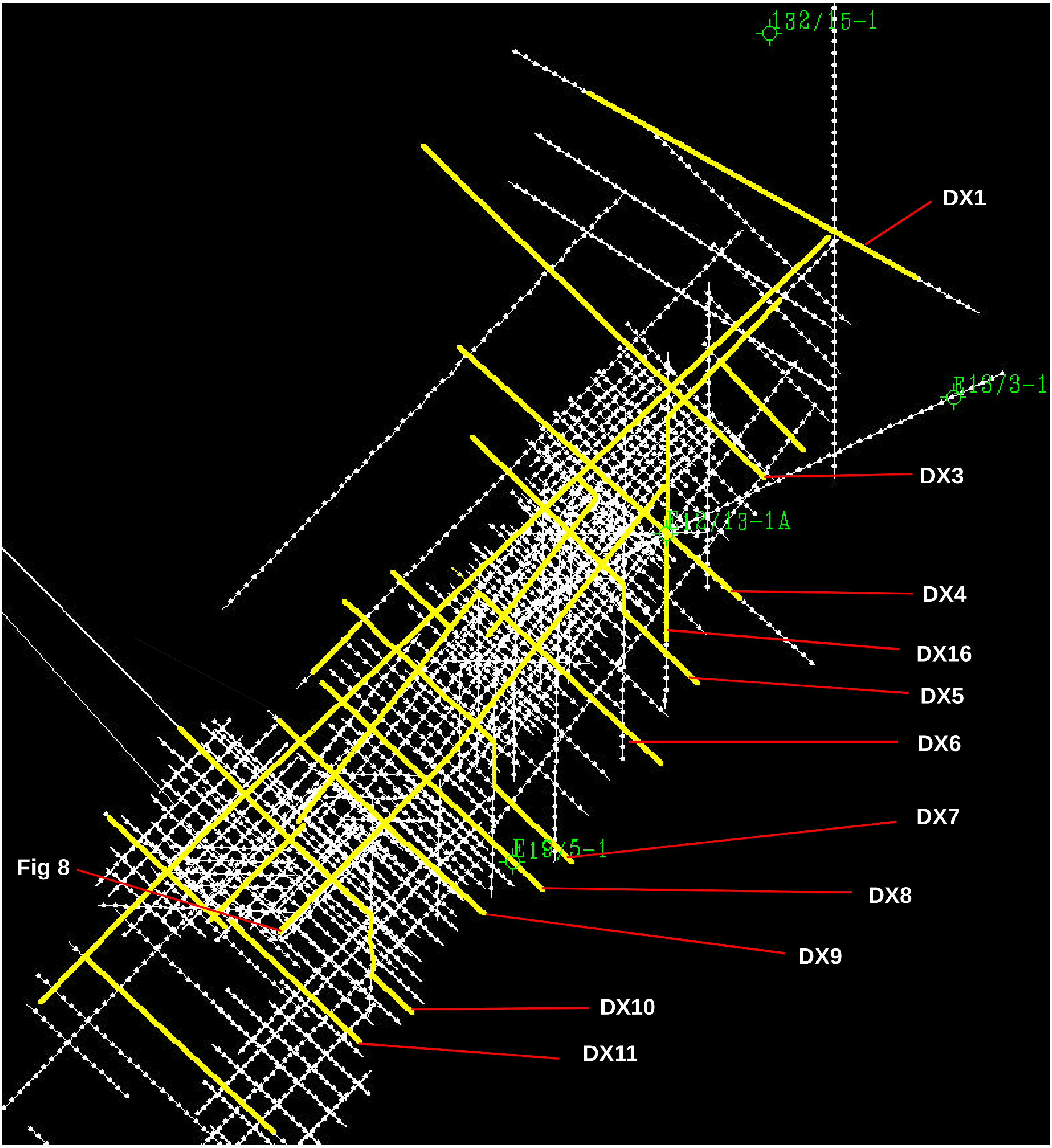
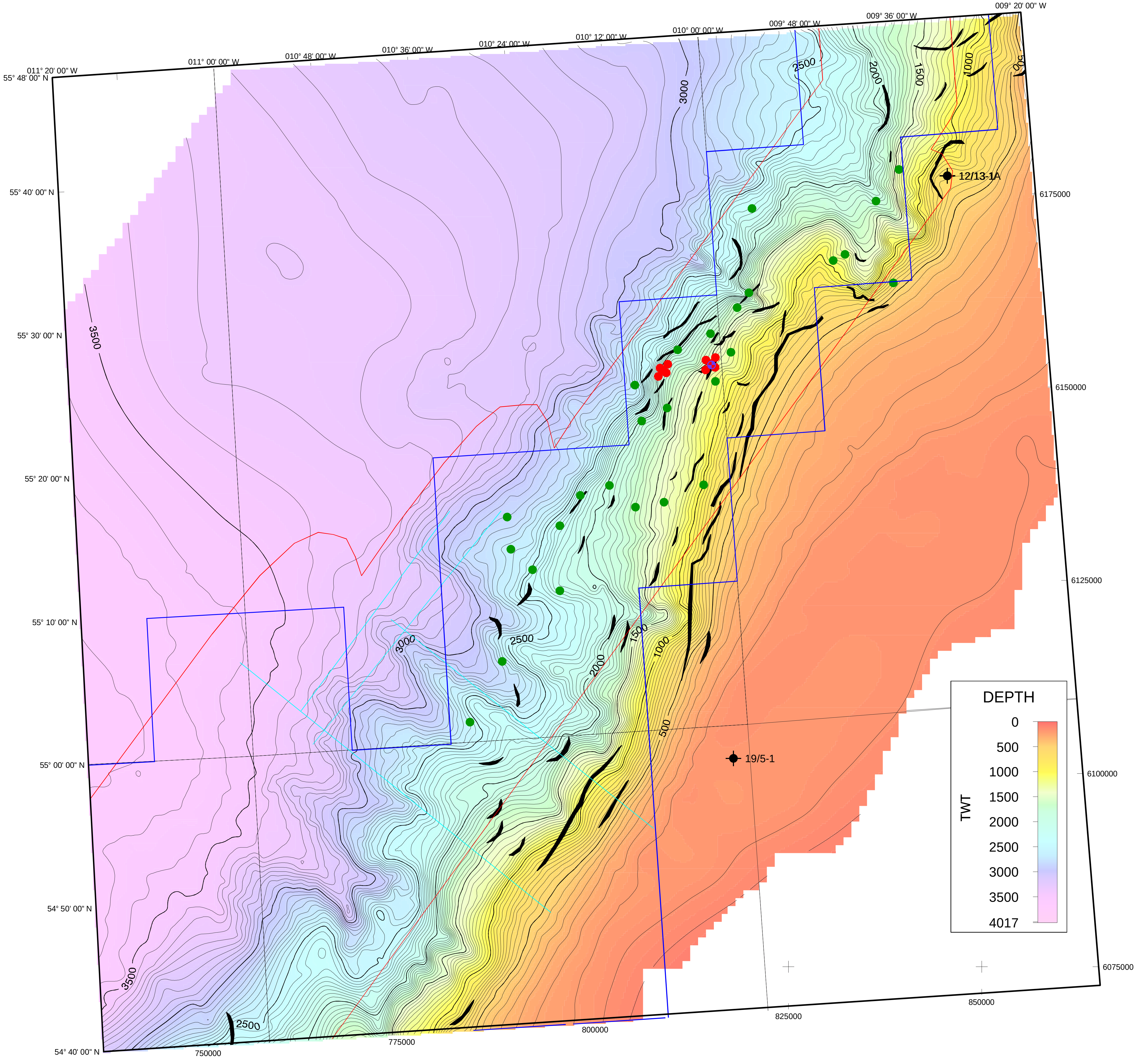


Figure 4(c) Location map of Geoseismic Profiles



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HYDROSEARCH

Legend

- Wells
- BGS Gravity cores
- Shallow drilling location
- Geoboy Cores
- NIOZ 2000 seismic lines
- Faults cutting seabed
- TRIM coverage

NOTES

Grid cell size = 500m

C.I.= 50 msecs

Contours annotated every 500 msecs

Values are in two way travel time taken from interpreted seabed pick from RSG 2000 2D exploration dataset

Integrated bathymetry (in depth) covering this region can be found in RSG Project 00/7.

1:500000

0 8 16 24 32 40

KILOMETRES

Universal Transverse Mercator Projection, Zone 28 N
International 1924 Spheroid
Central Meridian 15 W
Map Sheet Datum: ED50 Common Offshore

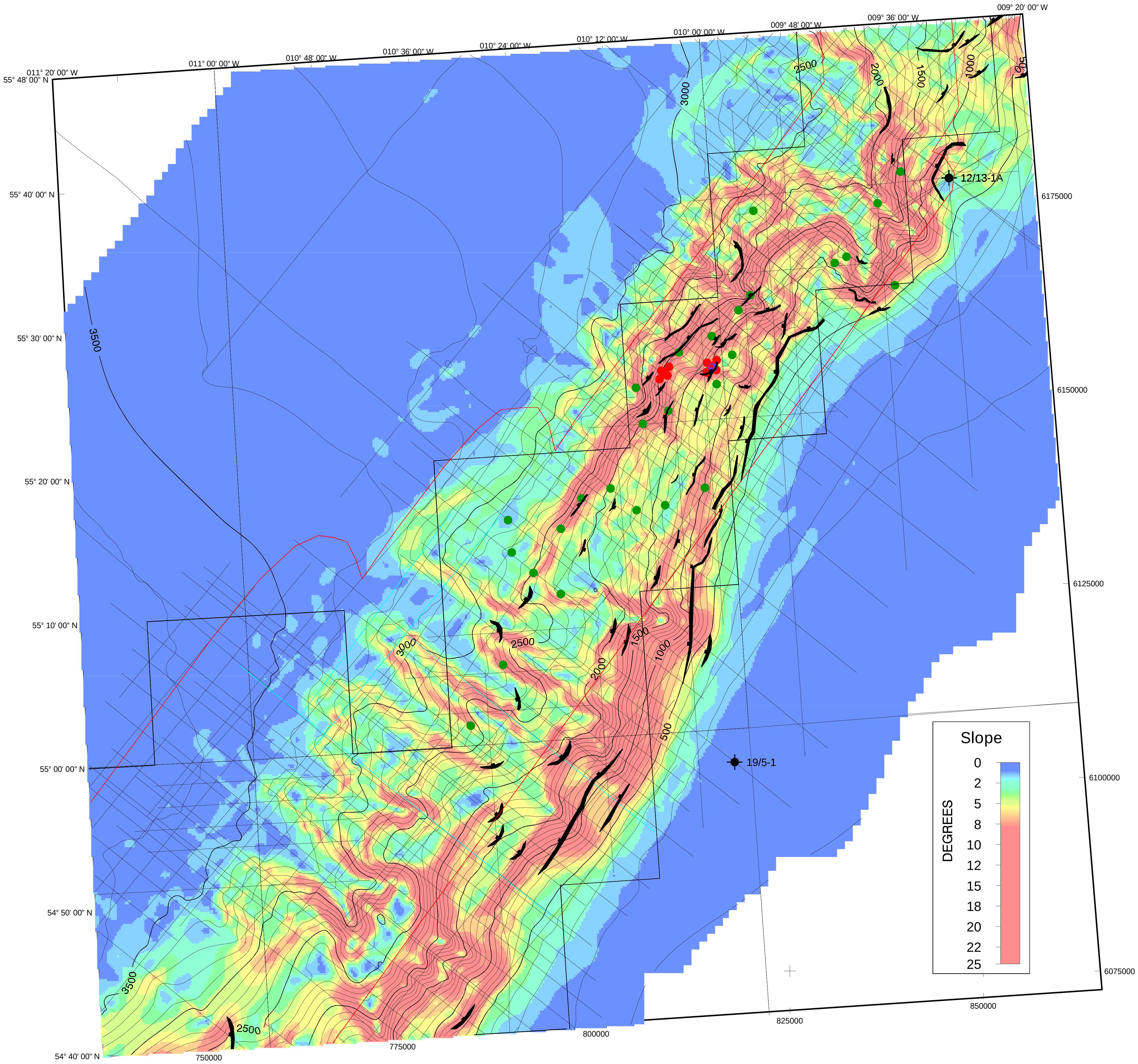
Hydrosearch Associates Ltd

Figure 5

BATHYMETRY MAP

(TWT)

Author: BJA CW NSW	Date: May 20, 2002
RSG Project 00/6	Revision: Final BJA



Petroleum Infrastructure Programme
Rockall Studies Group

HYDROSEARCH

Legend

Wells	
BGS Gravity cores	
Shallow drilling location	
Geoboy Cores	
Seismic lines	
NIOZ 2000 seismic lines	
TRIM coverage	

NOTES

Cell Size = 500m

1:500000

0 8 16 24 32 40

KILOMETRES

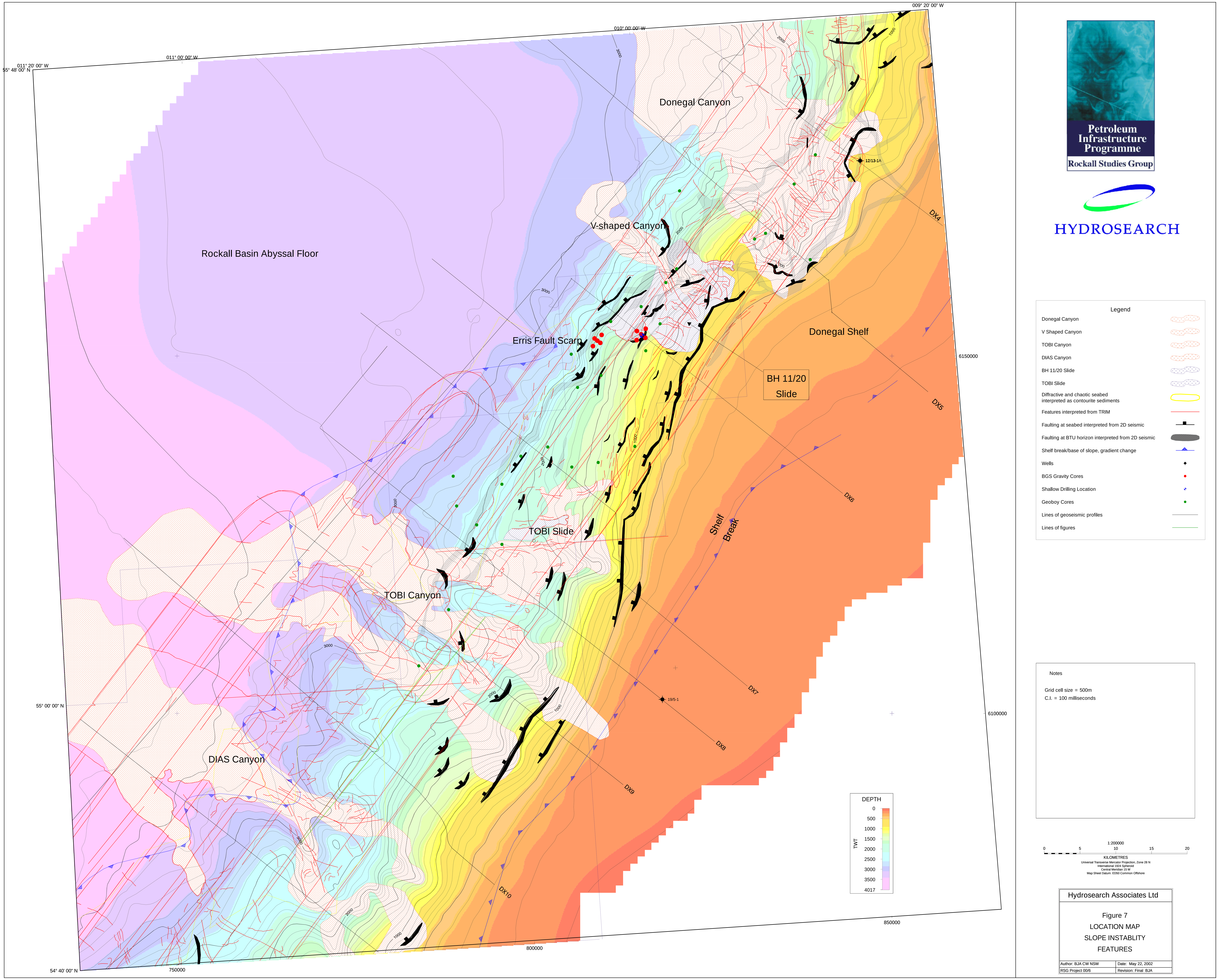
Universal Transverse Mercator Projection, Zone 28 N
International 1924 Spheroid
Central Meridian 15 W
Map Sheet Datum: ED50 Common Offshore

Hydrosearch Associates Ltd

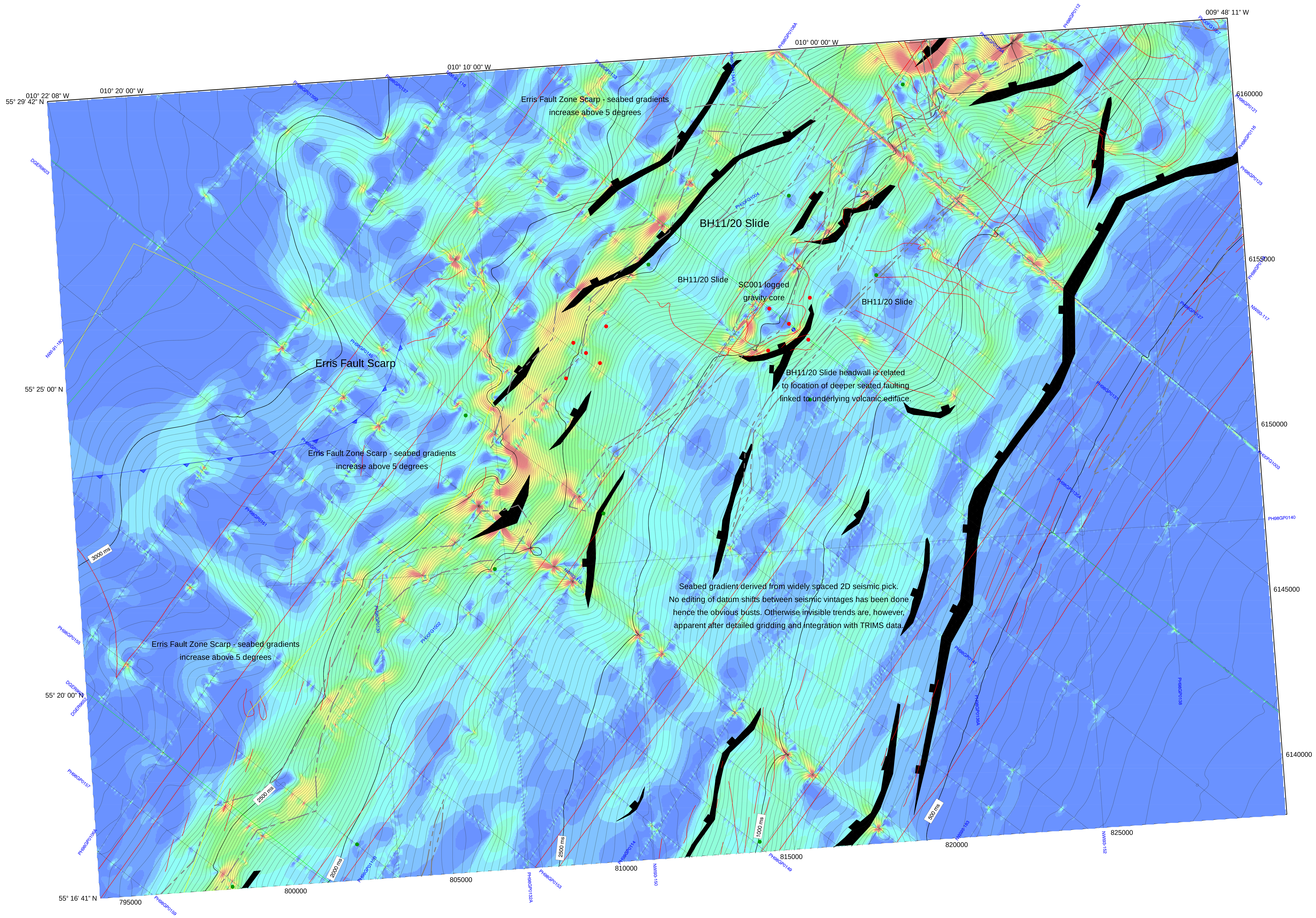
Figure 6

SEABED SLOPE

Author: BJA CW NSW	Date: May 20, 2002
RSG Project 00/6	Revision: Final BJA



011° 20' 00" W
55° 48' 00" N
011° 00' 00" W
010° 00' 00" W
009° 20' 00" W
Donegal Canyon
V-shaped Canyon
Rockall Basin Abyssal Floor
Erris Fault Scarp
Donegal Shelf
BH 11/20
Slide
TOBI Slide
TOBI Canyon
DIAS Canyon
Shelf
Break
12/13-1A
19/5-1
DX4
DX5
DX6
DX7
DX8
DX9
DX10
6150000
6100000
55° 00' 00" N
54° 40' 00" N
750000
800000
850000
DEPTH
TWT
0
500
1000
1500
2000
2500
3000
3500
4017
Petroleum
Infrastructure
Programme
Rockall Studies Group
HYDROSEARCH
Legend
Donegal Canyon
V Shaped Canyon
TOBI Canyon
DIAS Canyon
BH 11/20 Slide
TOBI Slide
Diffractive and chaotic seabed
interpreted as contourite sediments
Features interpreted from TRIM
Faulting at seabed interpreted from 2D seismic
Faulting at BTU horizon interpreted from 2D seismic
Shelf break/base of slope, gradient change
Wells
BGS Gravity Cores
Shallow Drilling Location
Geoboy Cores
Lines of geoseismic profiles
Lines of figures
Notes
Grid cell size = 500m
C.I. = 100 milliseconds
1:200000
0
5
10
15
20
KILOMETRES
Universal Transverse Mercator Projection, Zone 28 N
International 1924 Spheroid
Central Meridian 15 W
Map Sheet Datum: ED50 Common Offshore
Hydrosearch Associates Ltd
Figure 7
LOCATION MAP
SLOPE INSTABLITY
FEATURES
Author: BJA CW NSW
Date: May 22, 2002
RSG Project 00/6
Revision: Final BJA



Petroleum Infrastructure Programme

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HYDROSEARCH

Legend

- Features interpreted from TRIMS
- Faulting at seabed interpreted from 2D seismic
- Faulting at BTU horizon interpreted from 2D seismic
- Shelf break/base of slope, gradient change
- Wells
- BGS Gravity Cores
- Shallow Drilling Locations
- Geoboy cores
- Geoseismic profiles
- Lines of Figures
- Footprint to scale of large WOS oilfield with complex lower slope environment reservoirs
- Underlying Erris trends

GRADIENT

Degrees: -0, 10, 20, 30, 40, 50, 60, 70, 80, 85

Notes

Cell Size = 500m

Challenger (BGS) Hi Res Seismic (not shown), covers area of BGS gravity cores

C.I. = 20 ms

1:50000

0 1 2 3 4

KILOMETRES

Universal Transverse Mercator Projection, Zone 28 N
International 1924 Spheroid
Central Meridian 15 W
Map Sheet Datum: ED50 Common Offshore

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Figure 7a

BH11/20 SLIDE

AREA SEABED SLOPE

Author: BJA, CW	Date: February 20, 2002
RSG Project 00/6	Revision: Final BJA

Figure 8 Showing regional truncation of composite C10, C20, C30 erosion surface

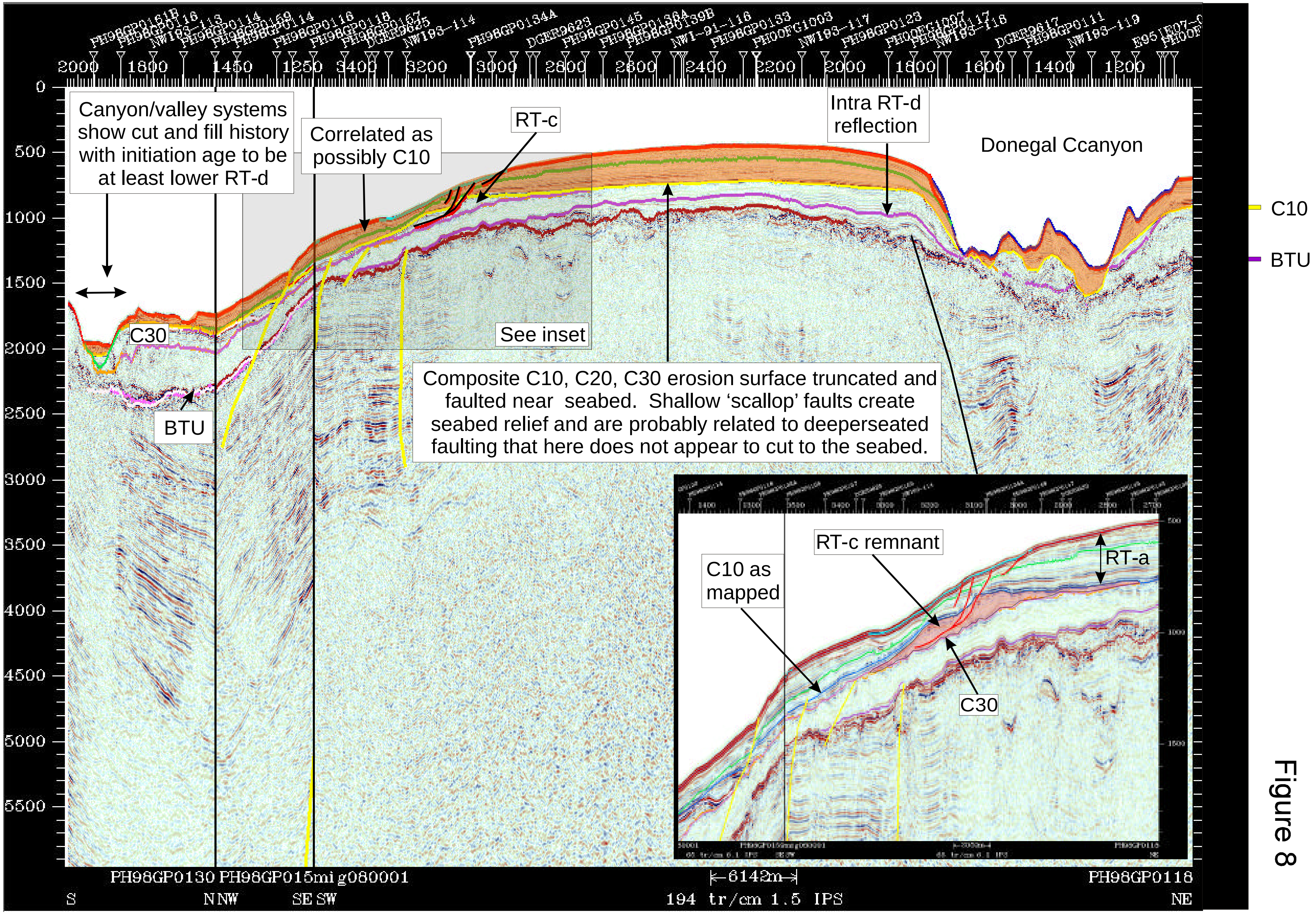


Figure 8

Figure 9 Fundamental influence of Erris Fault Zone on Slope Morphology.

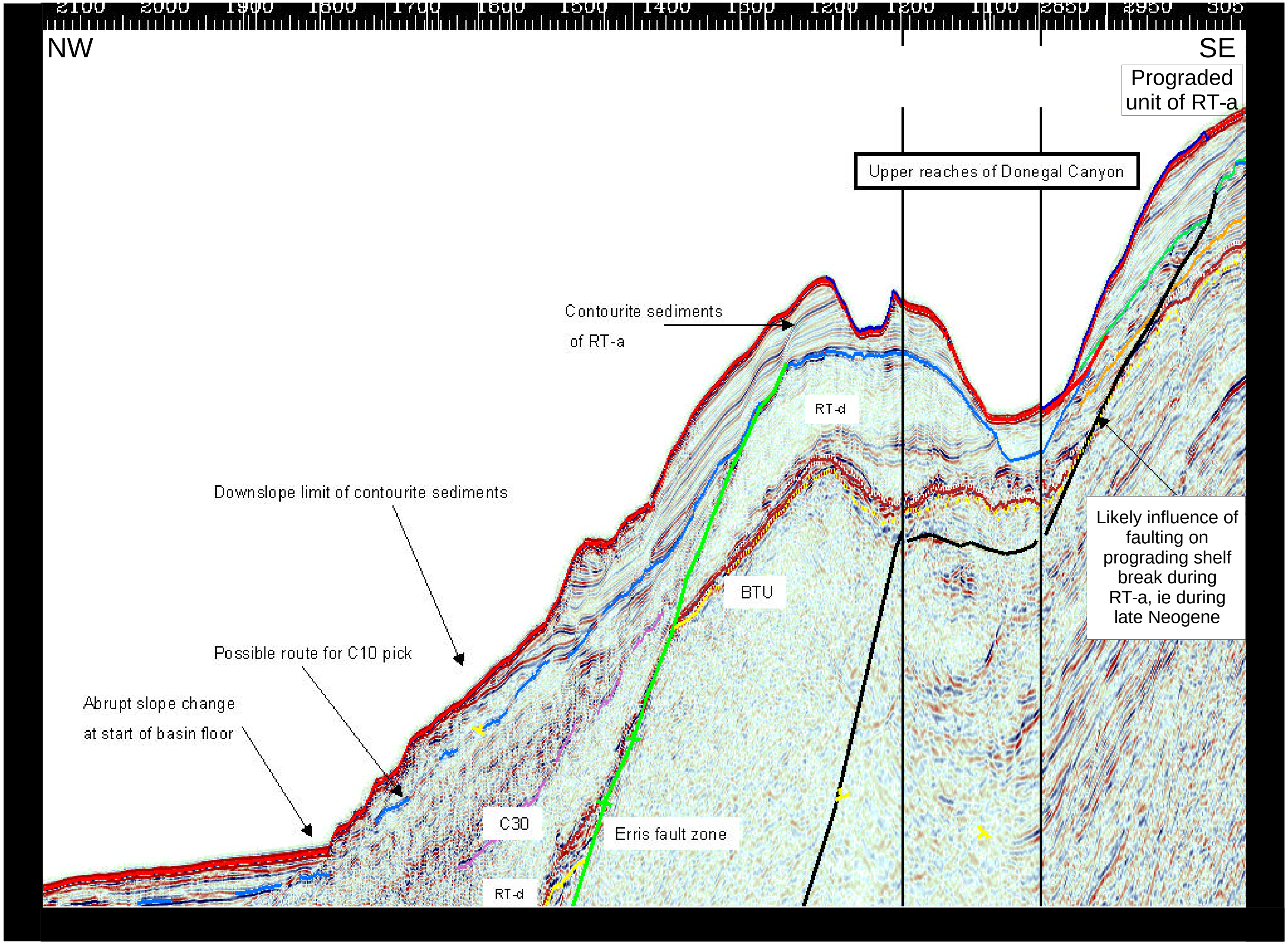


Figure 9

Figure 10

Slope instability directly related to low angle shallow ‘scallop’ faults.

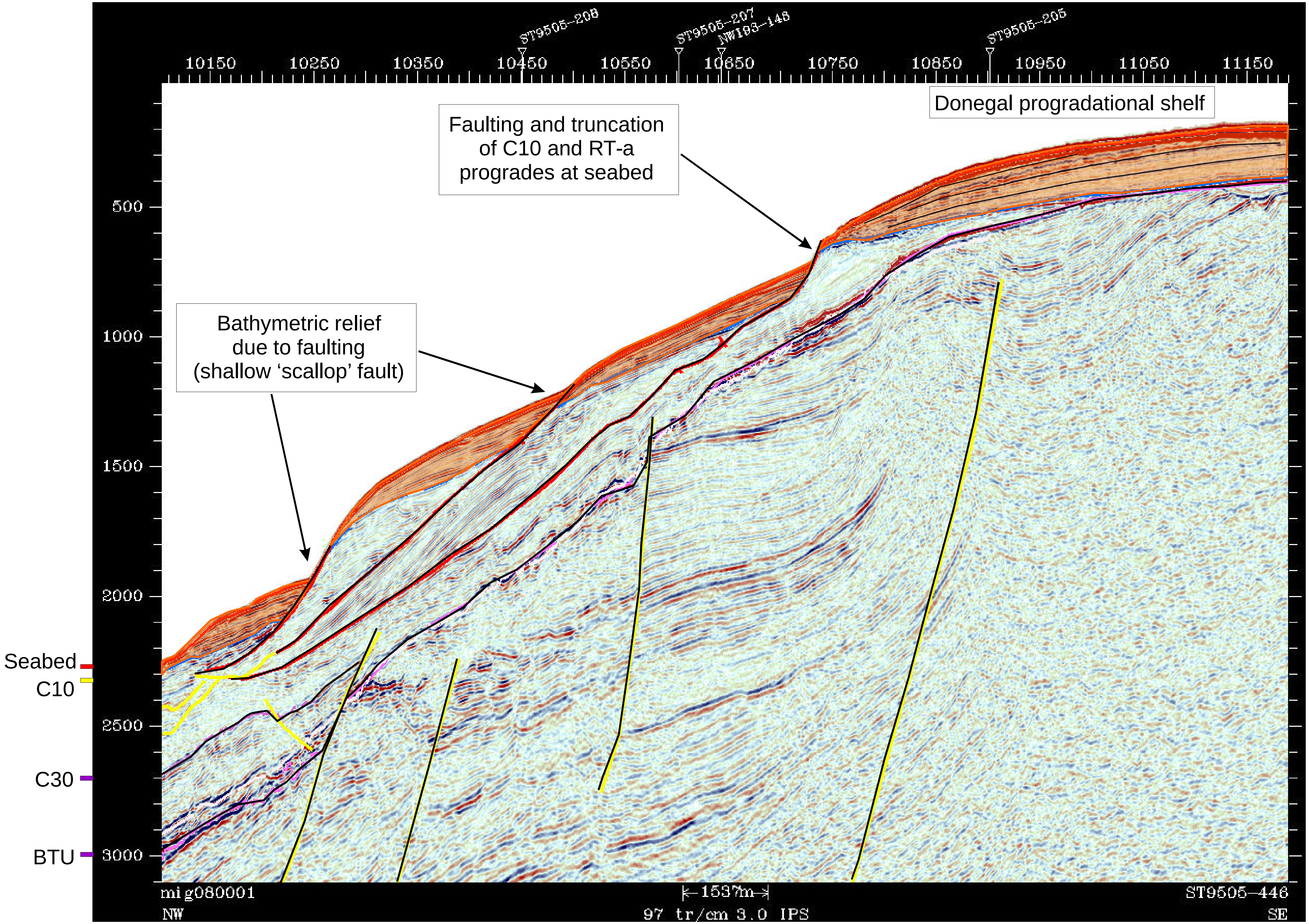


Figure 10

Figure 11

Slope instability apparently unrelated to fault movement.

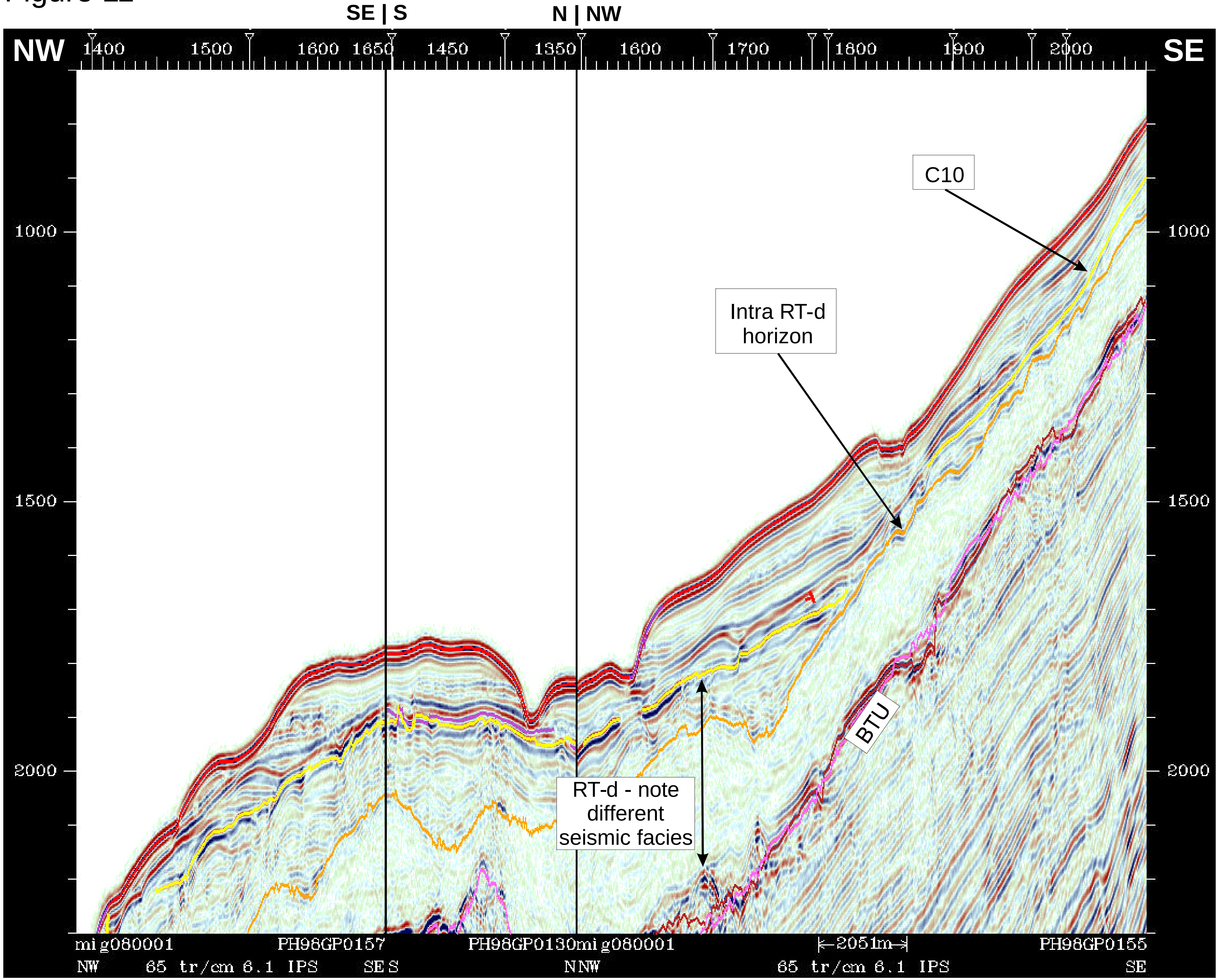


Figure 11

Figure 12

Faulted and rotated blocks of assumed RT-a age interpreted as having a cover of RT-a contourite sediments plastered upon them.

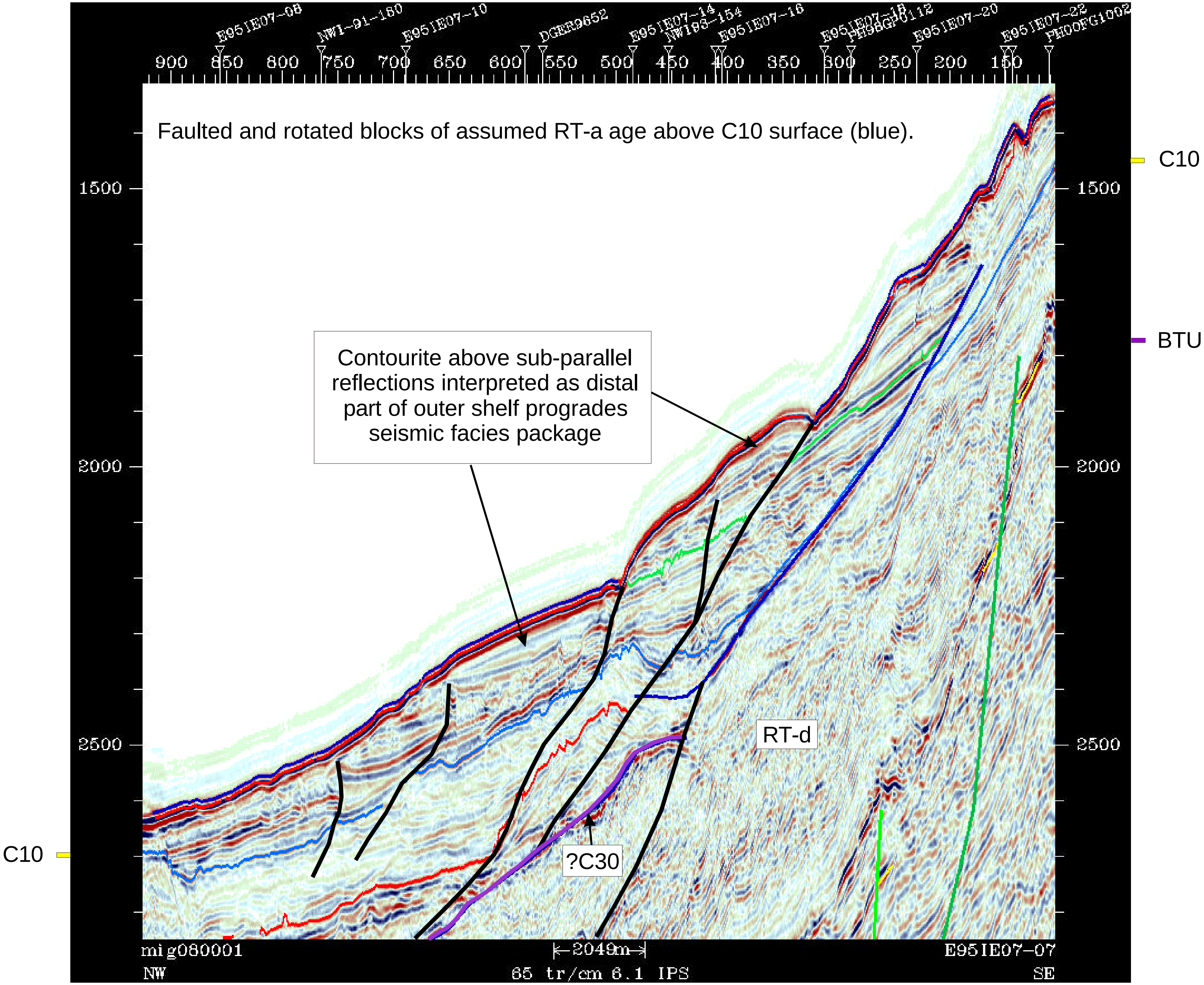


Figure 12

Figure 13

Showing composite nature of slope canyon/valley systems. See also composite canyons identified on Figure 34.

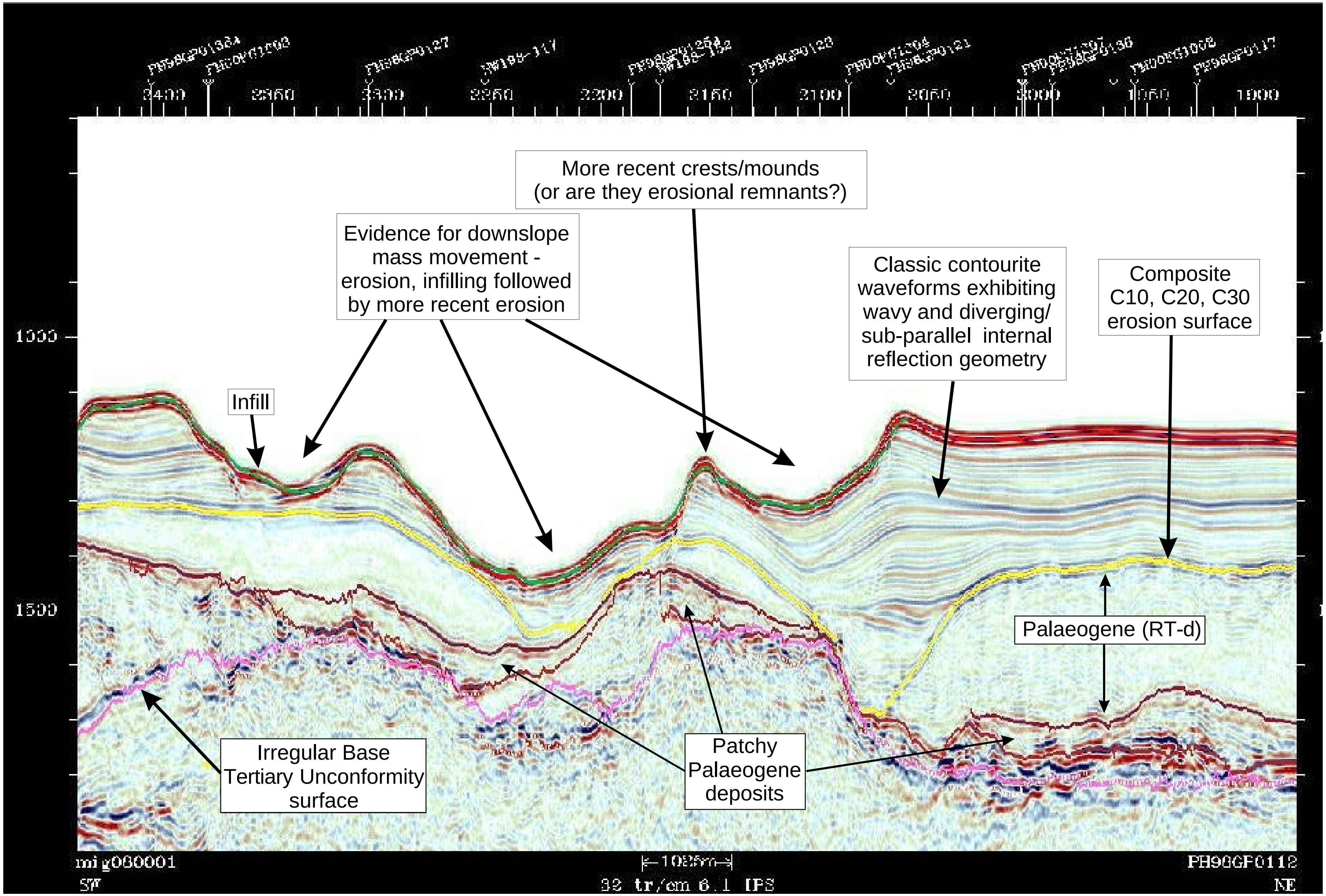


Figure 13

Figure 14 Interaction between suspected contourite and channel fill sediments in the NE ‘T’ Canyon system.

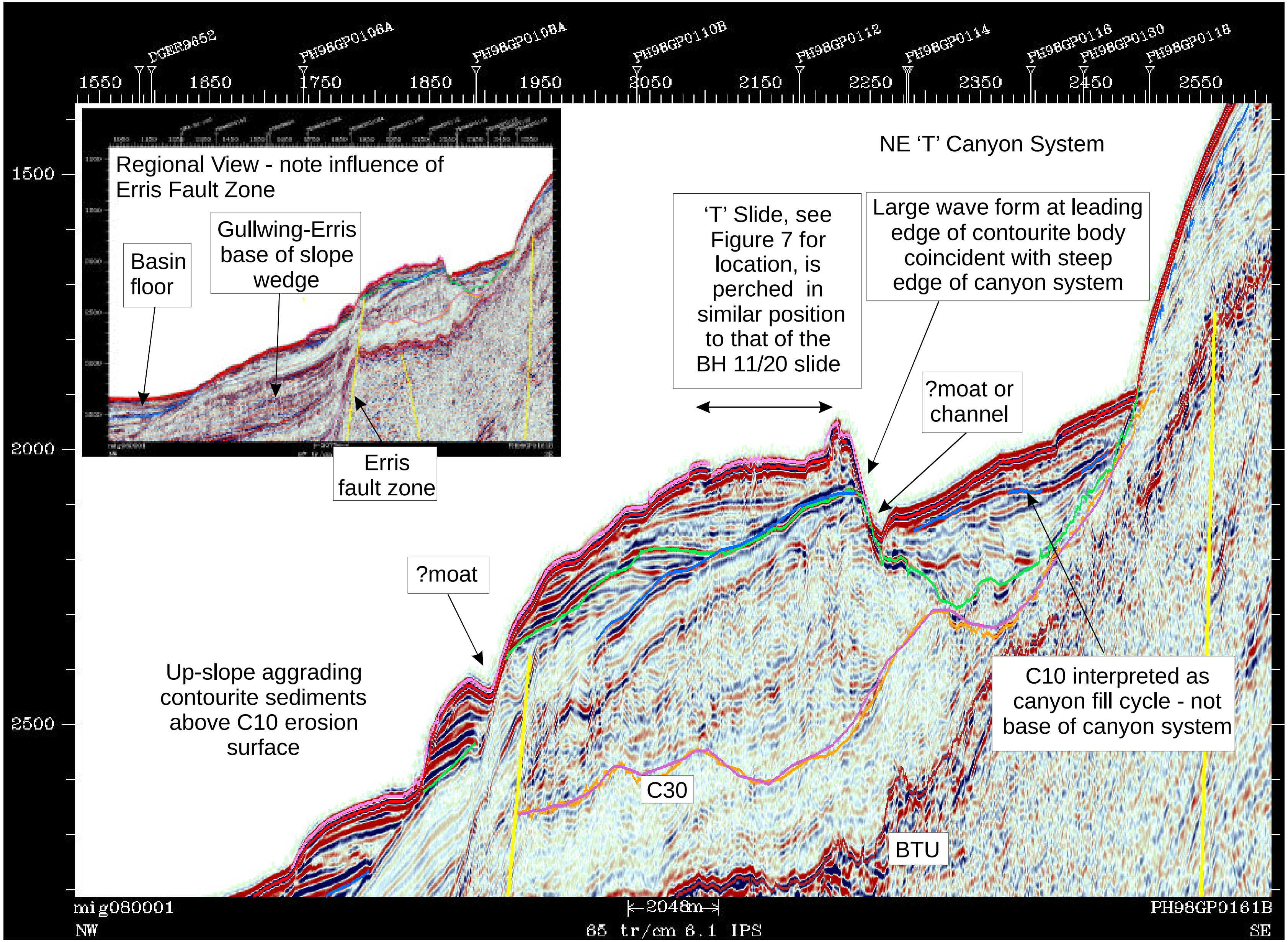


Figure 14

Figure 15 Donegal Canyon System cuts down into the Base Tertiary Unconformity surface.

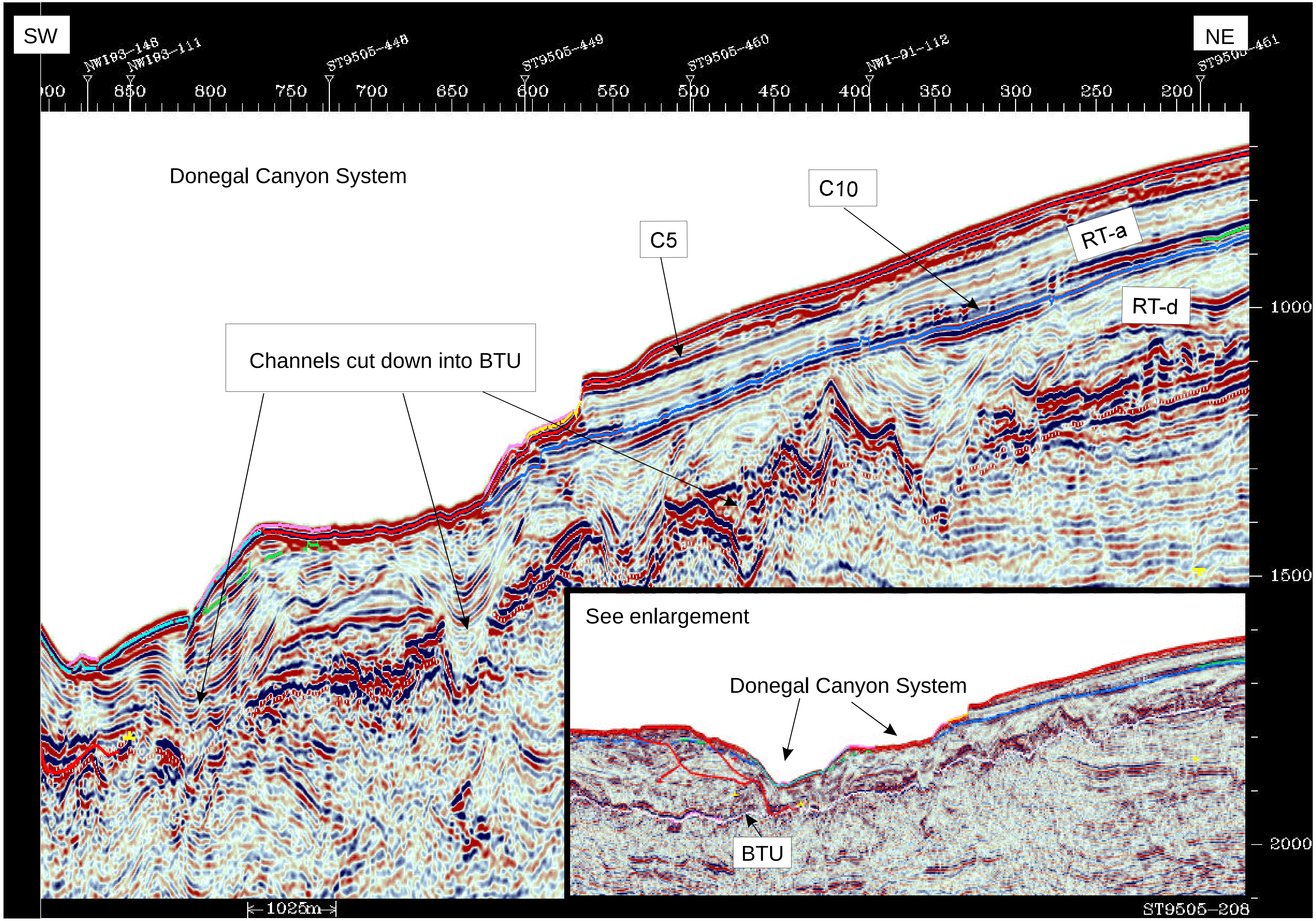


Figure 15

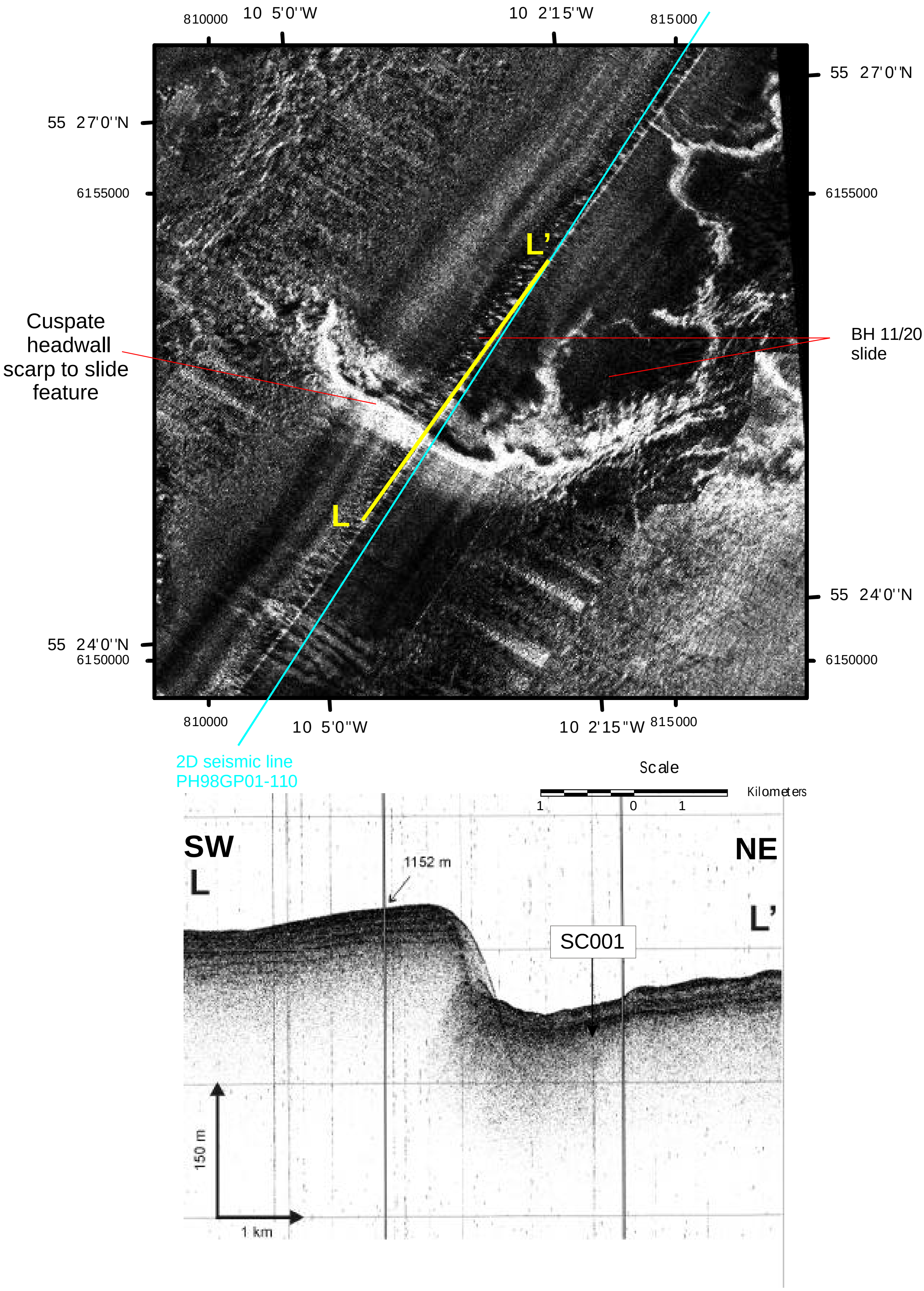


Figure 16 BH 11/20 slide imaged on TOBI and 3.5 kHz pinger data

Figure 17 Slope instability at the 11/20 borehole location showing relationship to underlying RT-d aged volcanism and location of gravity cores.

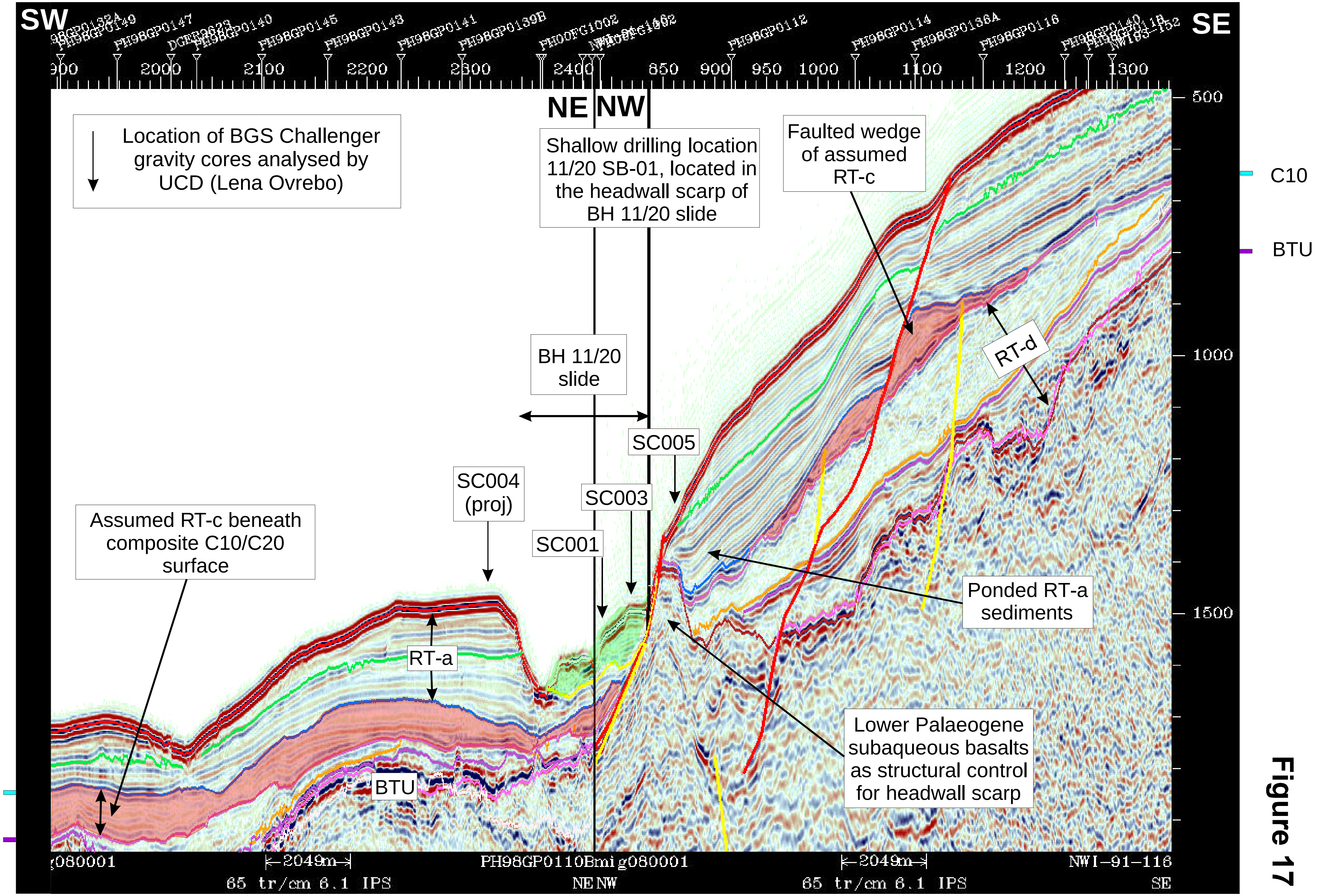


Figure 17

Figure 18 Example of high resolution seismic data through BH 11/20 slide

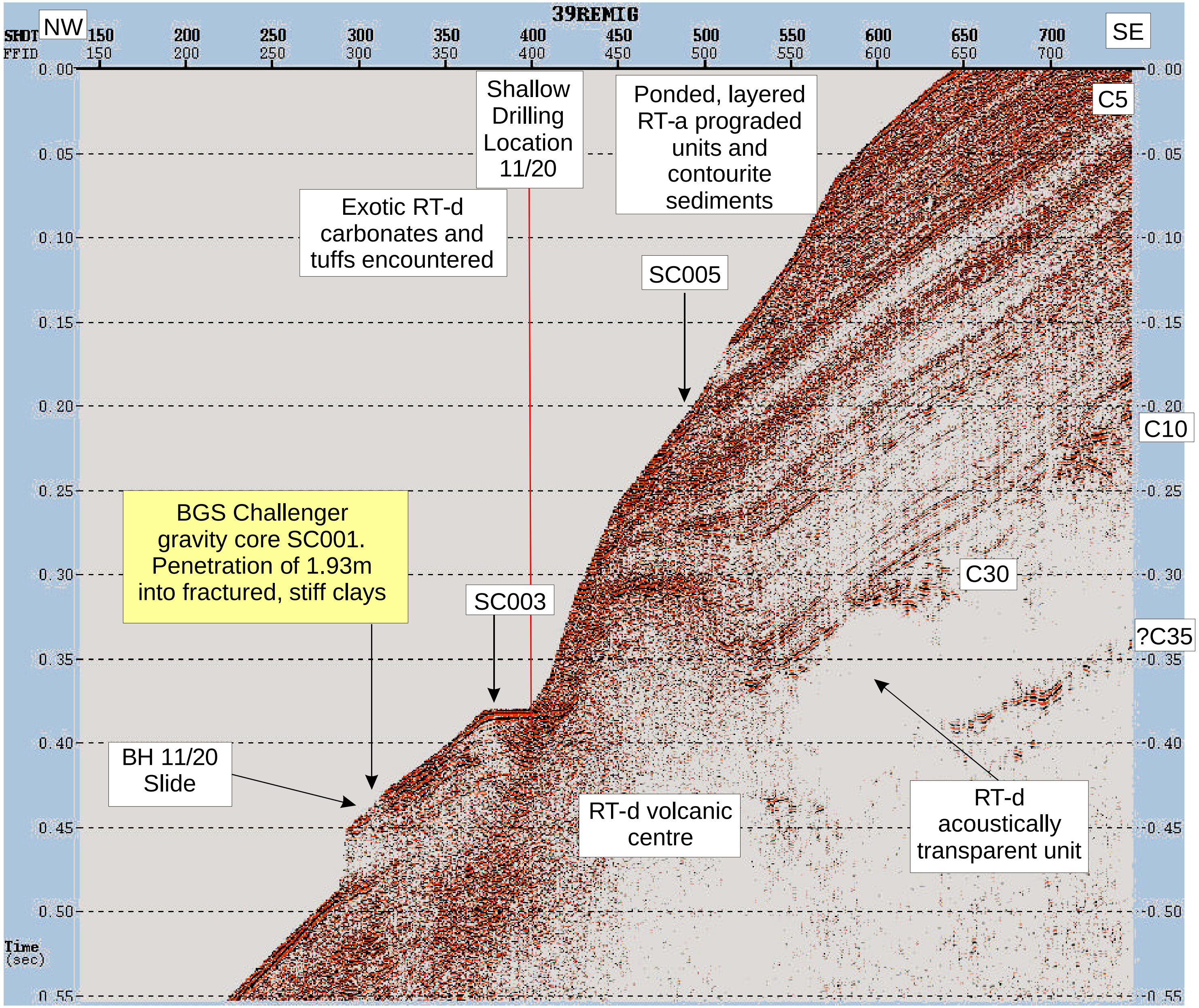


Figure 18

Figure 19

High resolution vs exploration 2D seismic data comparison

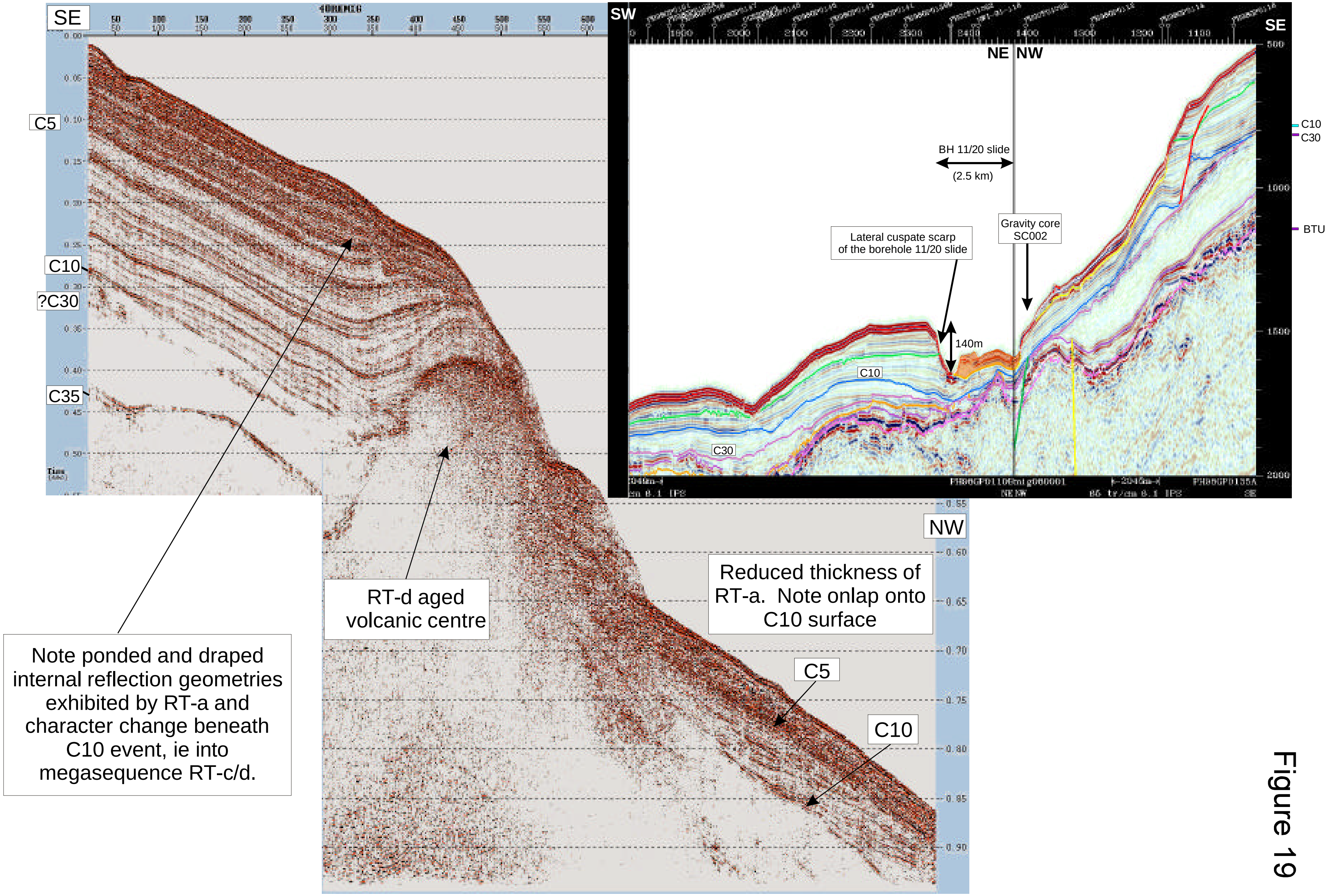


Figure 19

Figure 20 Location of BGS gravity core SC002 and lateral cuspate scarp

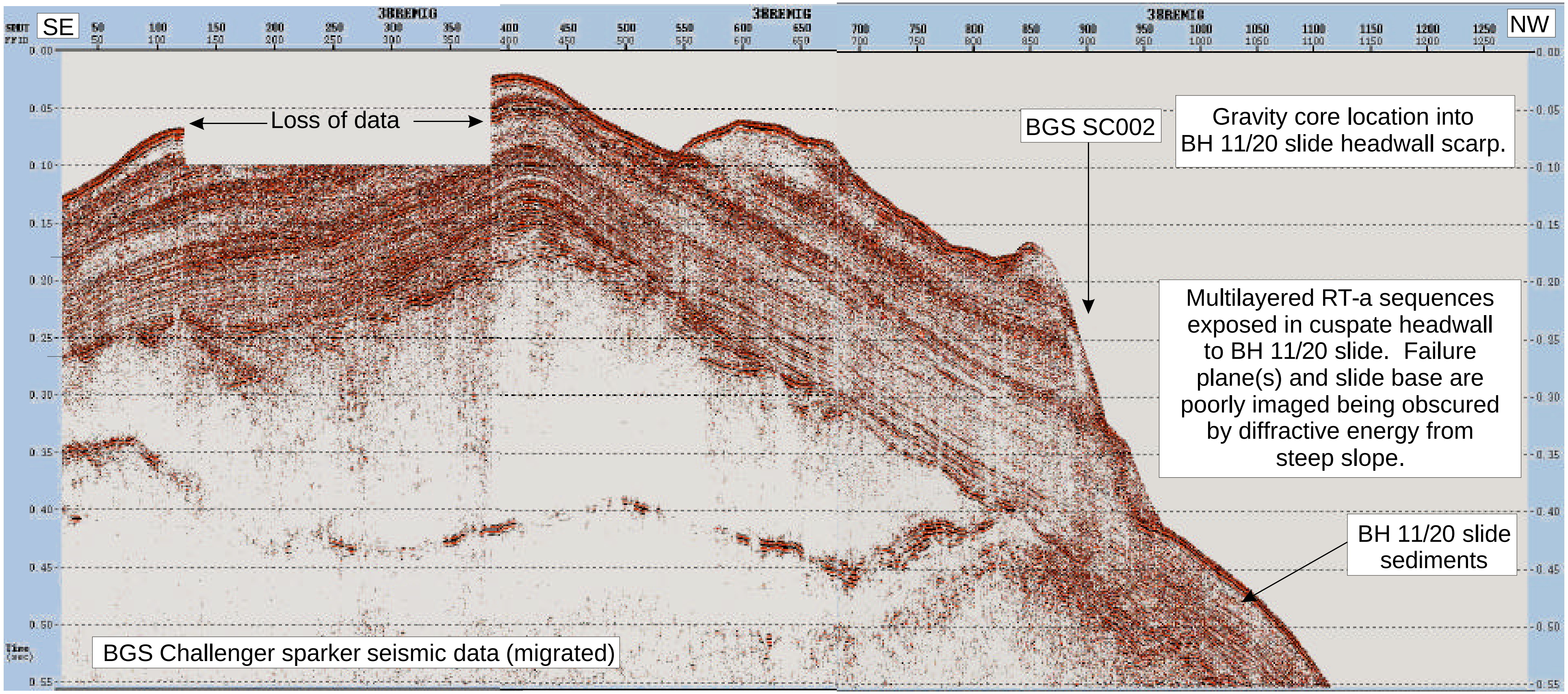


Figure 20

Figure 21 Showing the BH11/20 slide in its strike regional setting. NB Vertical Exaggeration is 16 times

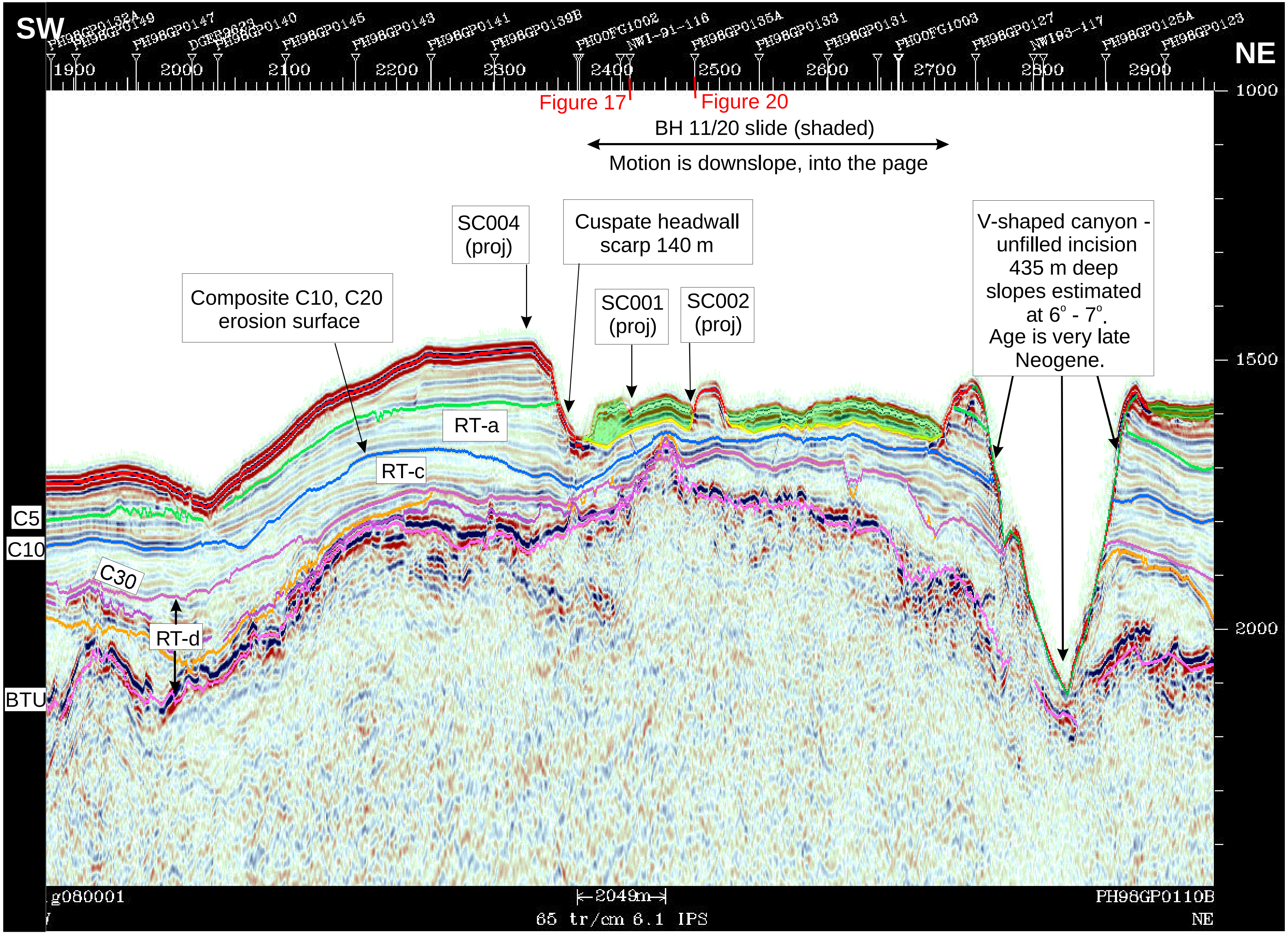


Figure 21

Figure 22

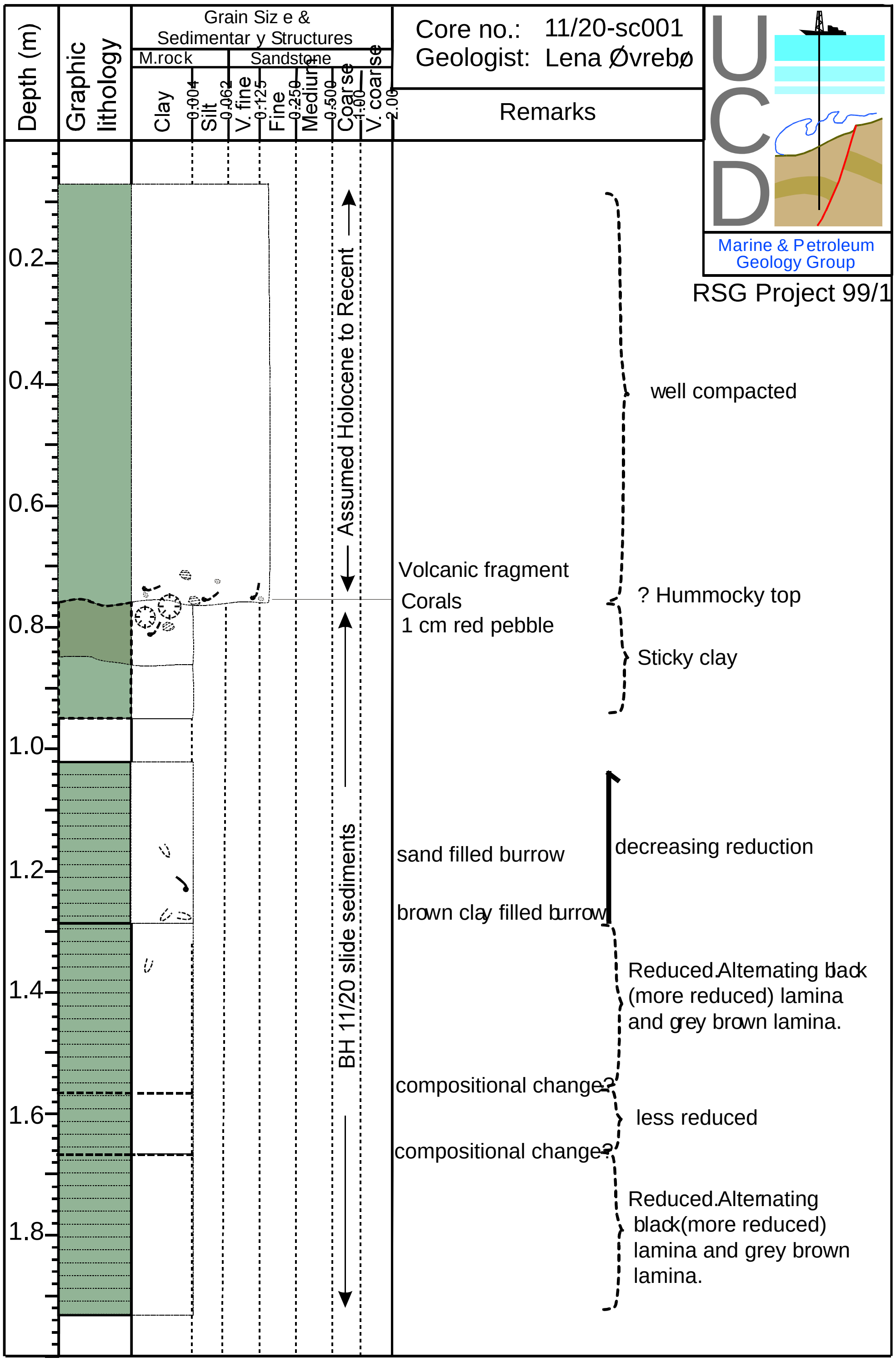


Figure 22 The location of Sc001within the BH 11/20 slide is shown in Figures 18,21 and 24. Beneath the surficial upper 76 cm of med dense clayey sand the core is uniformly a v. firm - stiff clay without clasts, interpreted to represent the uppermost portion of the BH 11/20 Slide that attains maximum thickness of some 56m. There are signs of a hummocky top and ?non horizontal laminae (visible due to reduction), possibly representing fractures caused during the inferred mass movement origin of the deposit.

Figure 23a

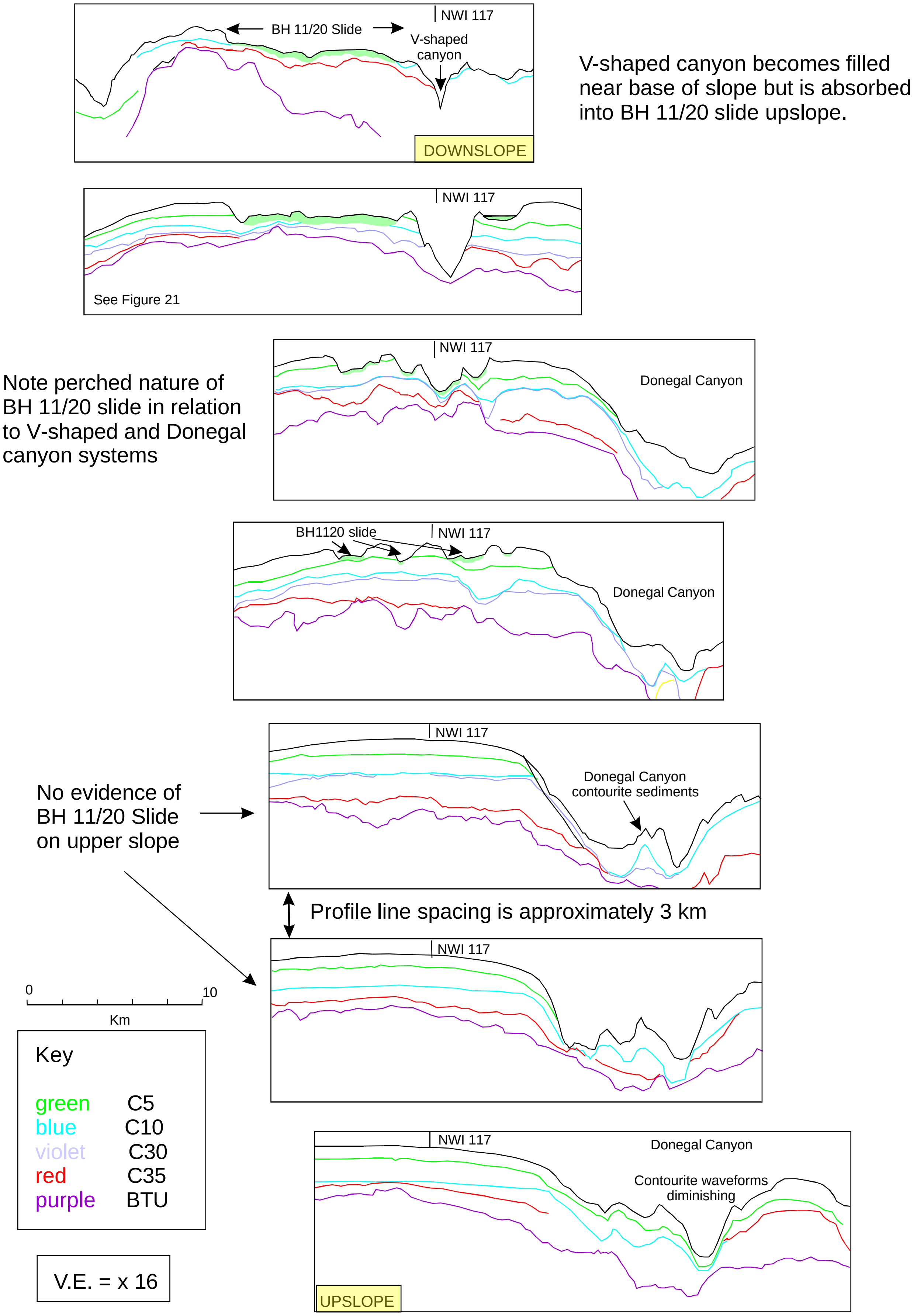
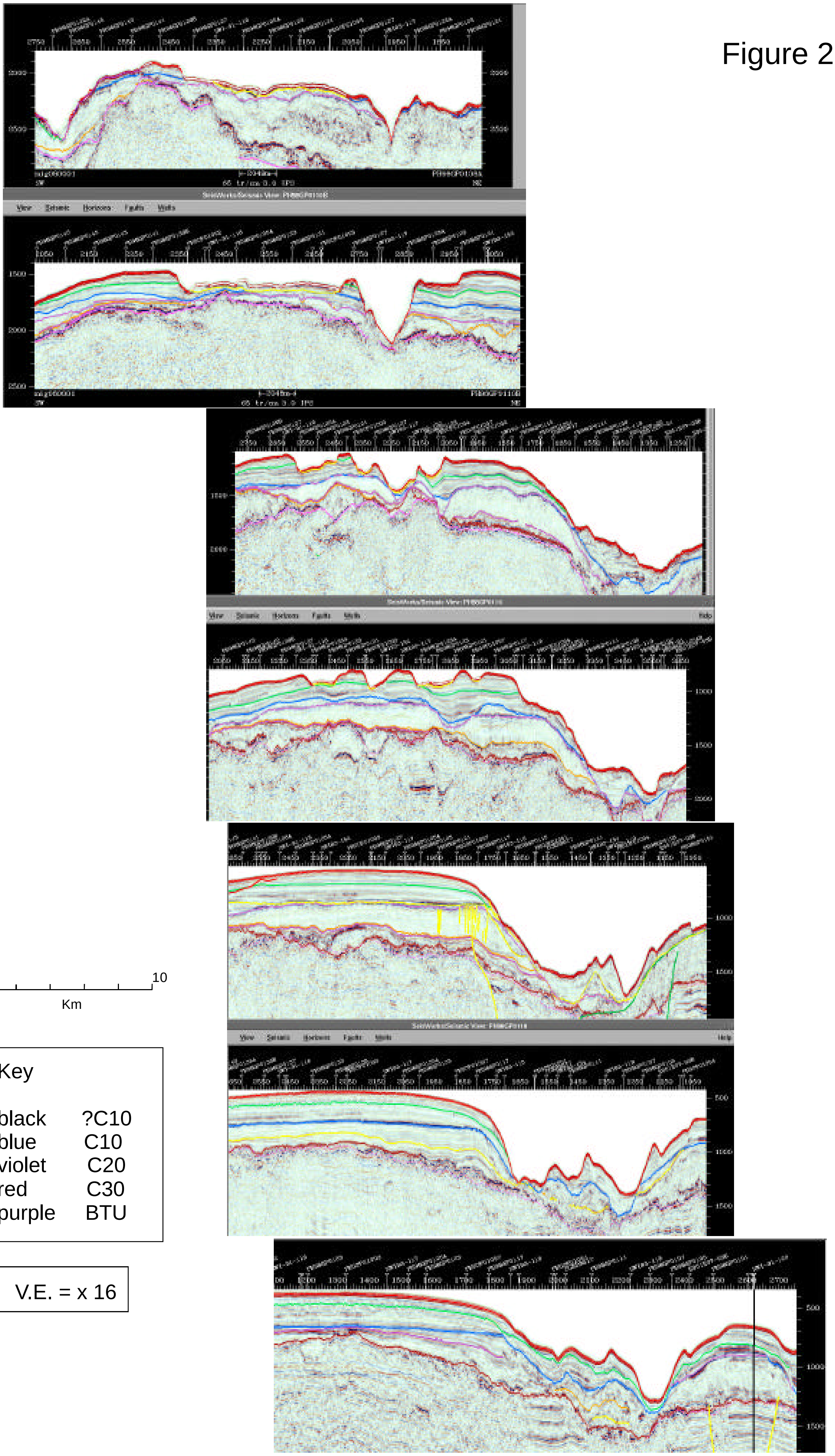


Figure 23a Interpreted profiles to illustrate relationships between seismic scale features and the BH 11/20 slide and V-shaped canyon observed during TRIM.

Figure 23b



0 10

Km

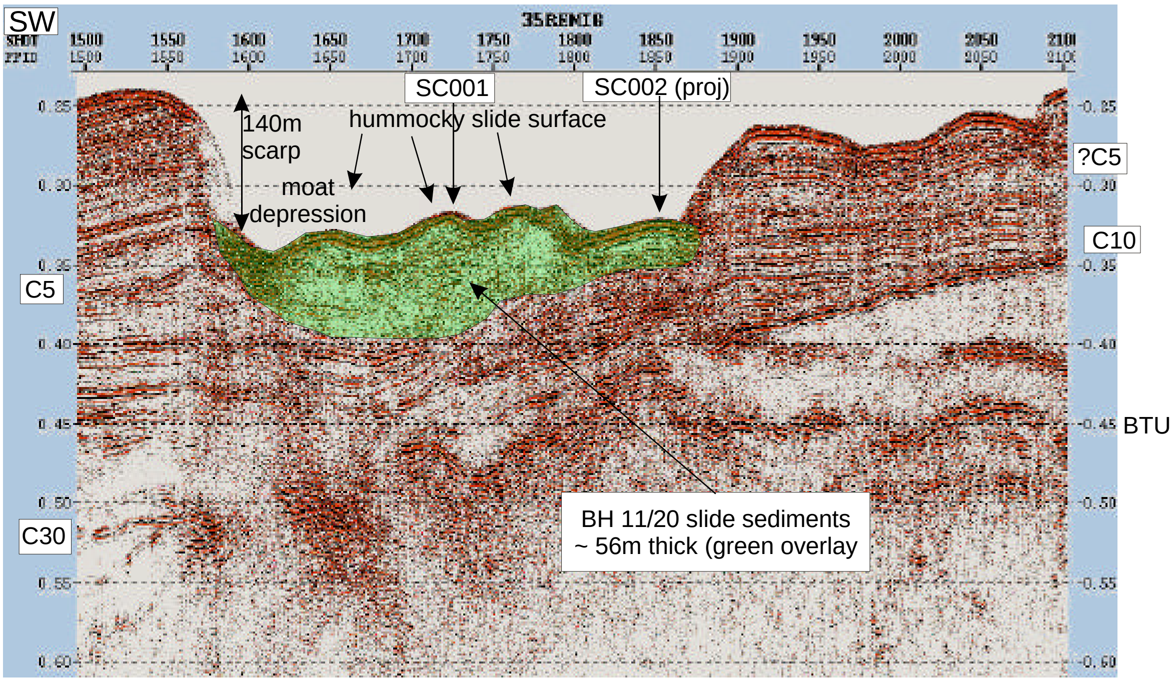
Key

black	?C10
blue	C10
violet	C20
red	C30
purple	BTU

V.E. = x 16

Figure 23b

Interpreted profiles to illustrate relationships between seismic scale features and the BH 11/20 slide and V-shaped canyon observed during TRIM.



Lines are ~300m apart

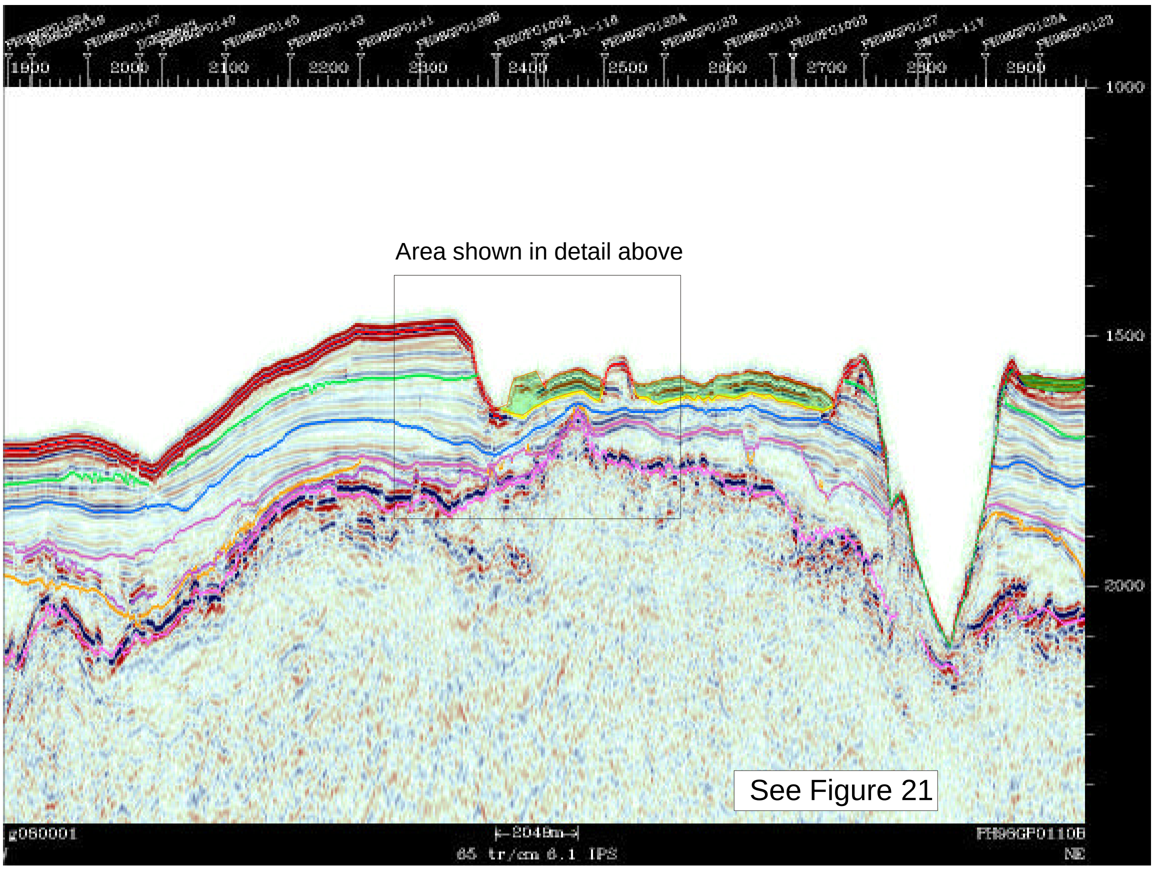


Figure 24 Data comparison between BGS High Resolution and exploration 2D seismic across BH 11/20 slide

Figure 25

Loop correlation using TOBI 2D seismic illustrating navigation instability.

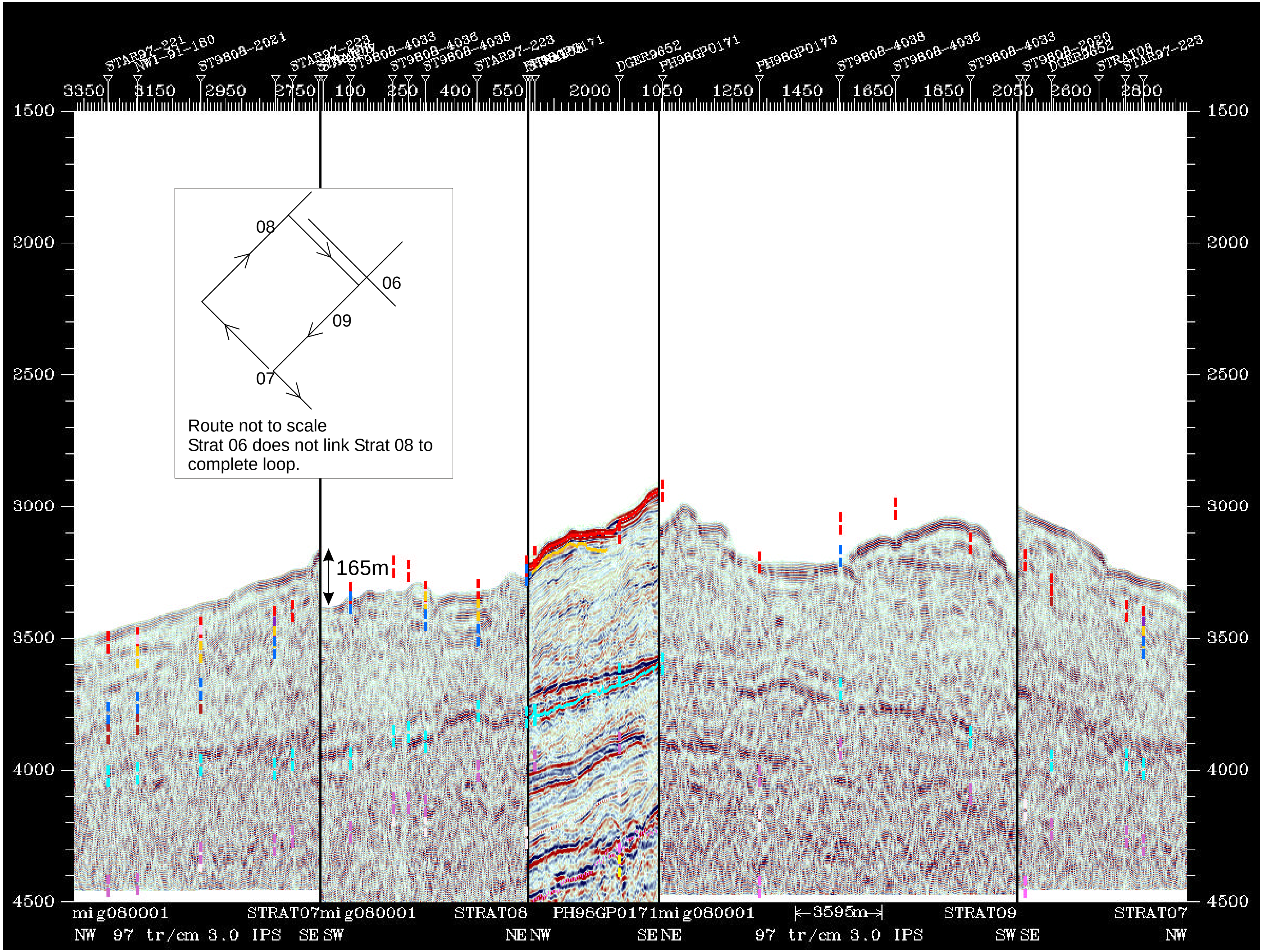


Figure 25

Figure 26 2D Seismic Interpretation of Donegal Canyon System. Line names refer to Figures 27 - 33

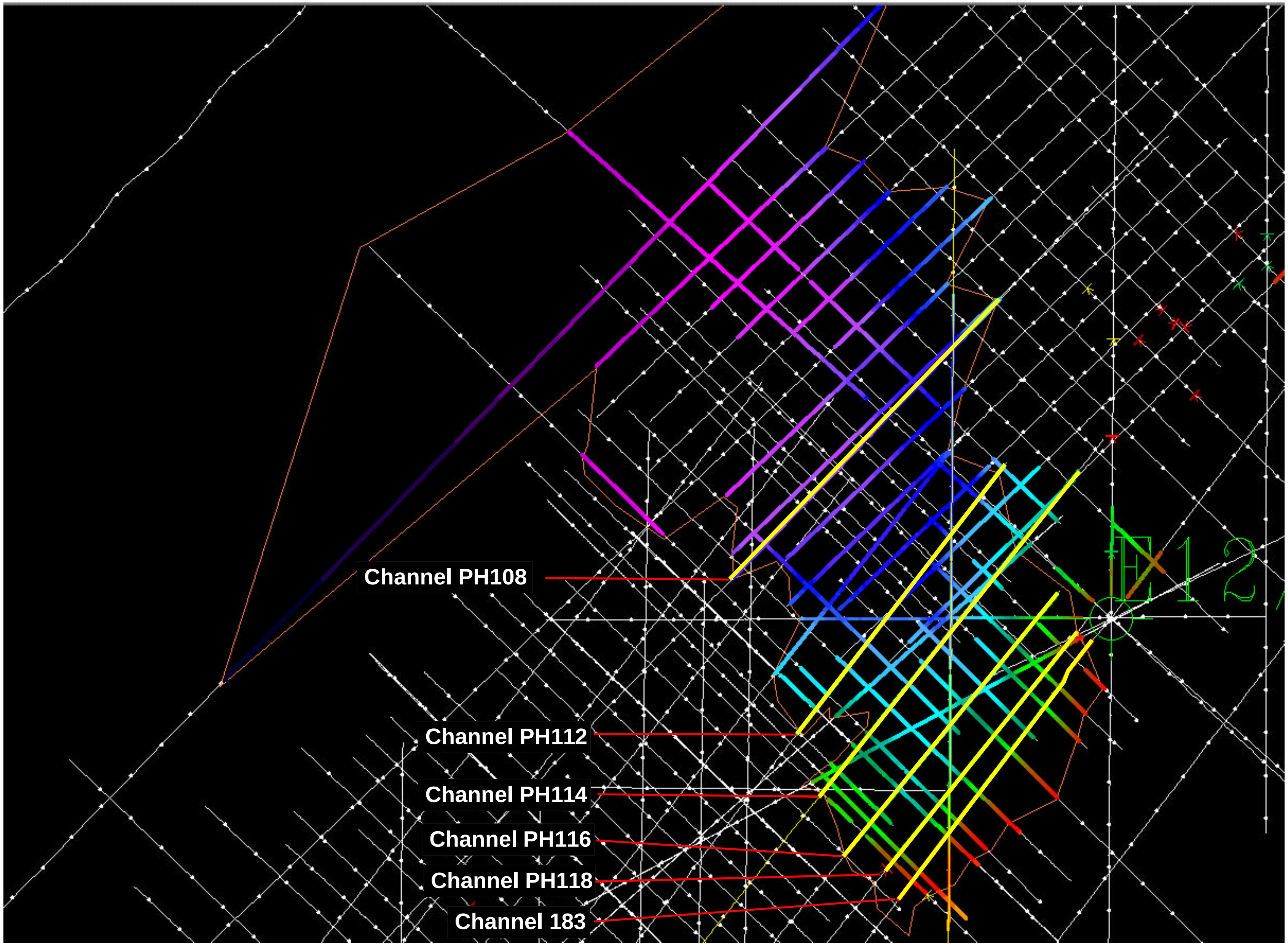


Figure 26

Figure 27a

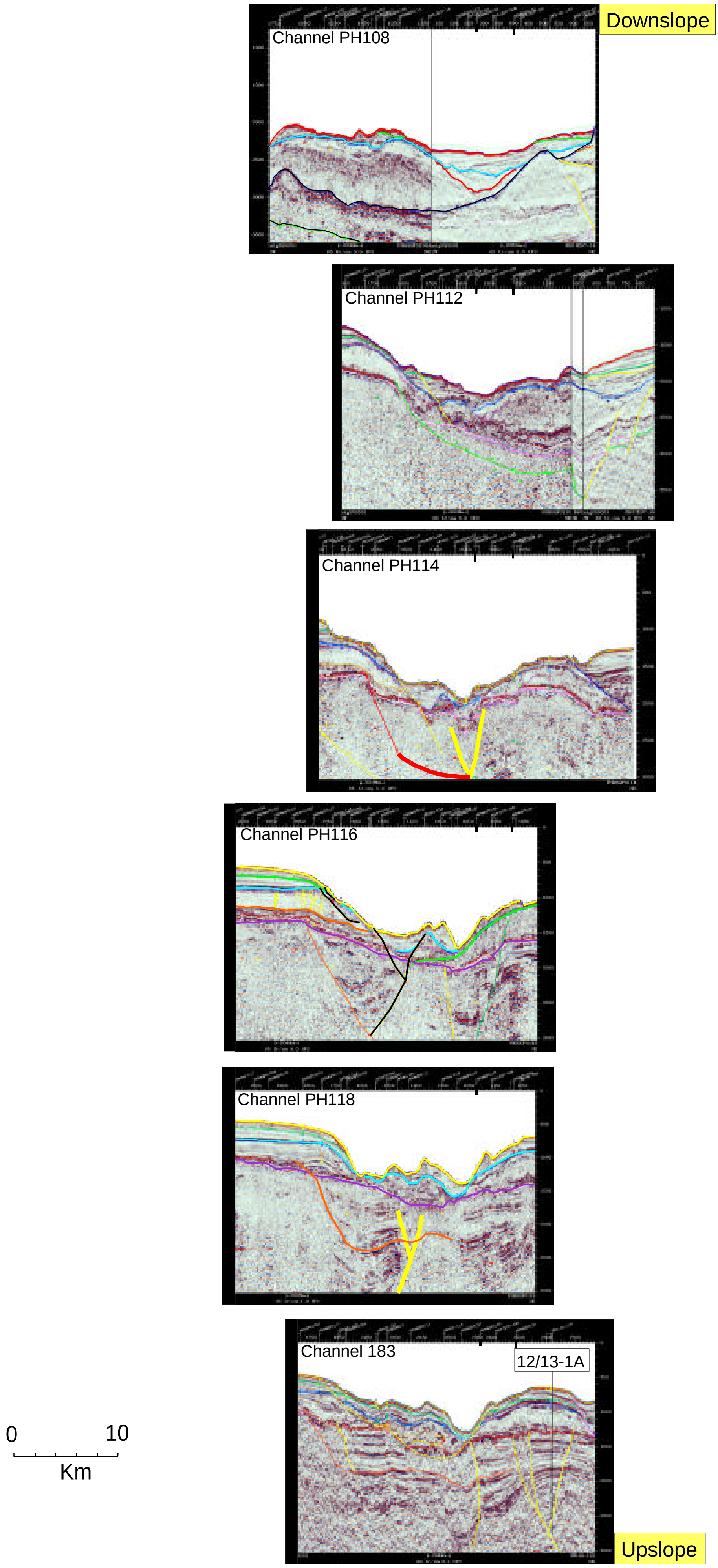


Figure 27a

Development of the Upper Reaches of the Donegal Canyon System

Figure 27b

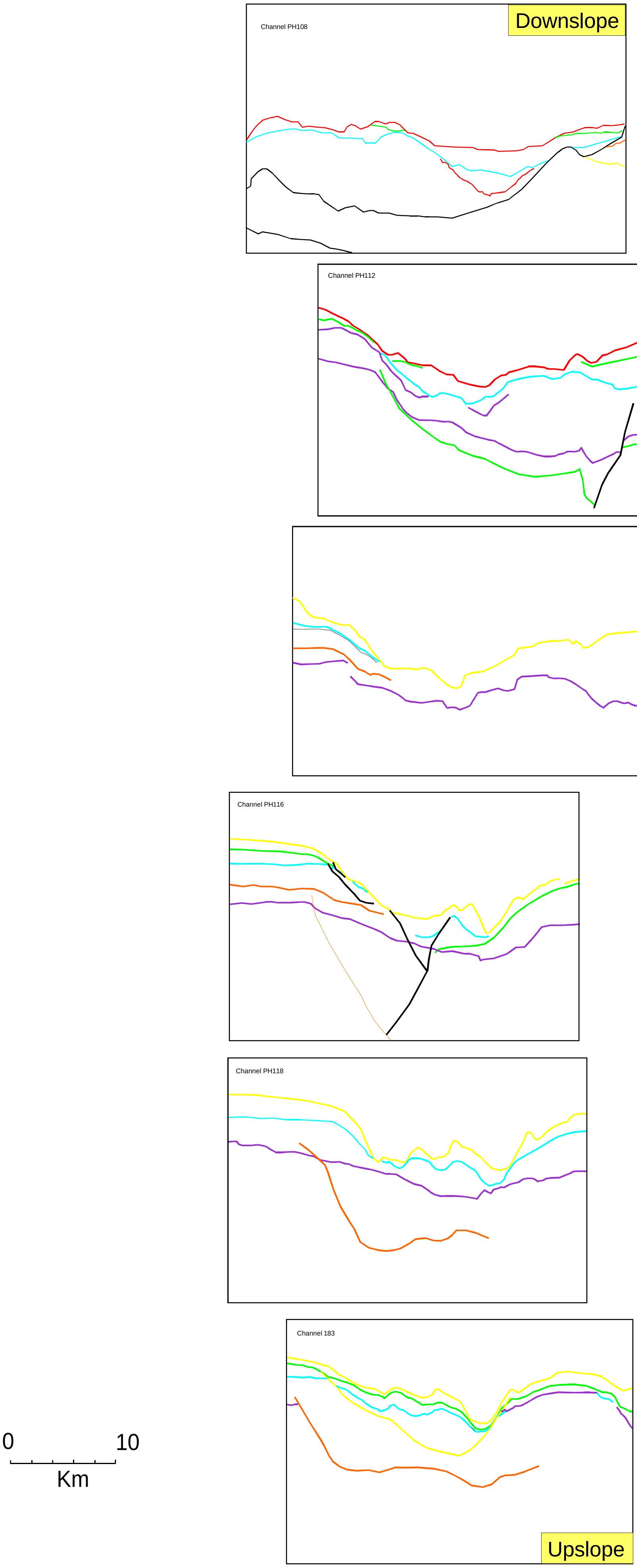


Figure 27b Development of the Upper Reaches of Donegal Canyon System

Figure 28 Example of composite canyon/channel erosion and fill with sidewall faulting.

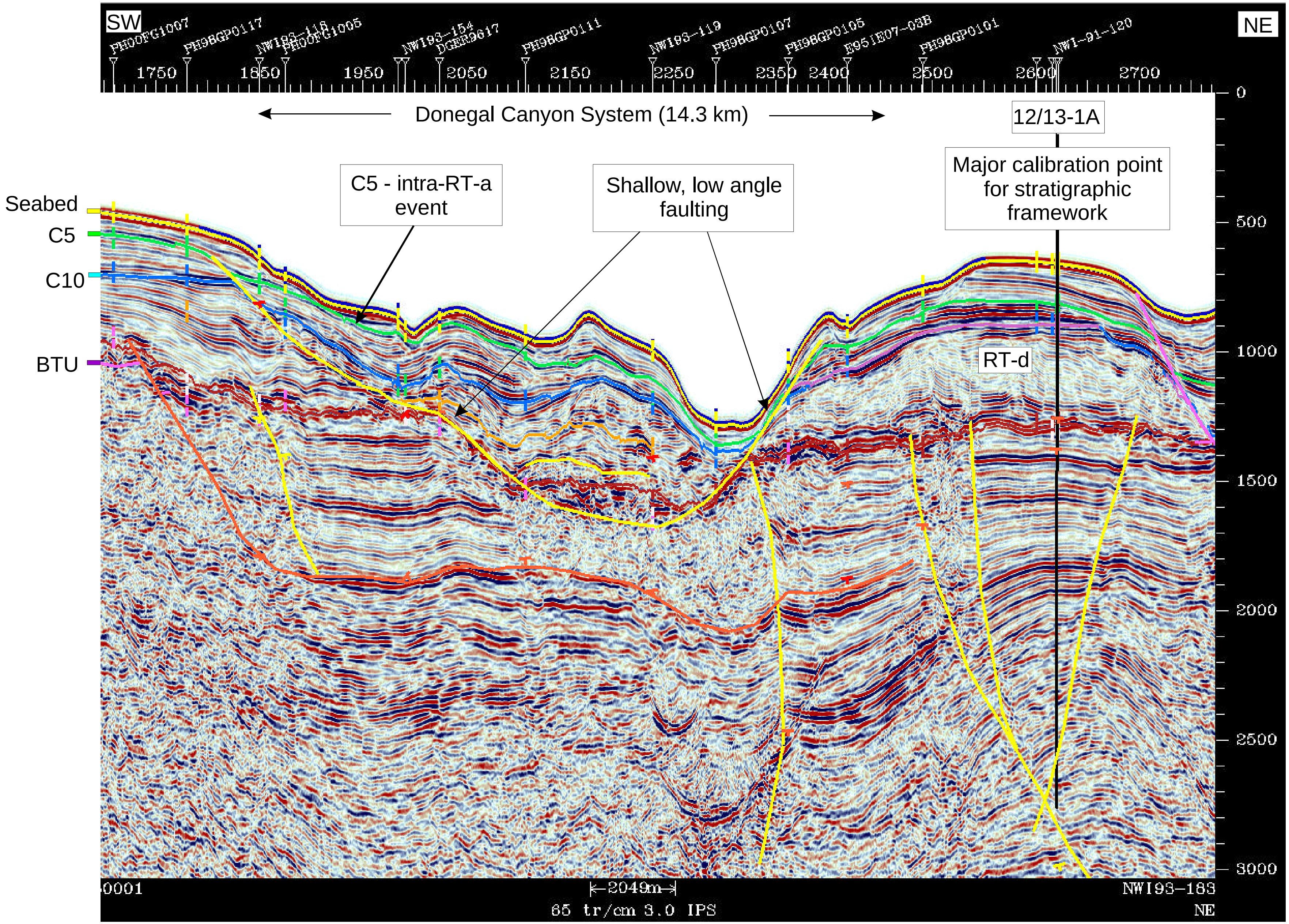


Figure 28

Figure 29 Example of interpreted contourite wave forms in Donegal Canyon.

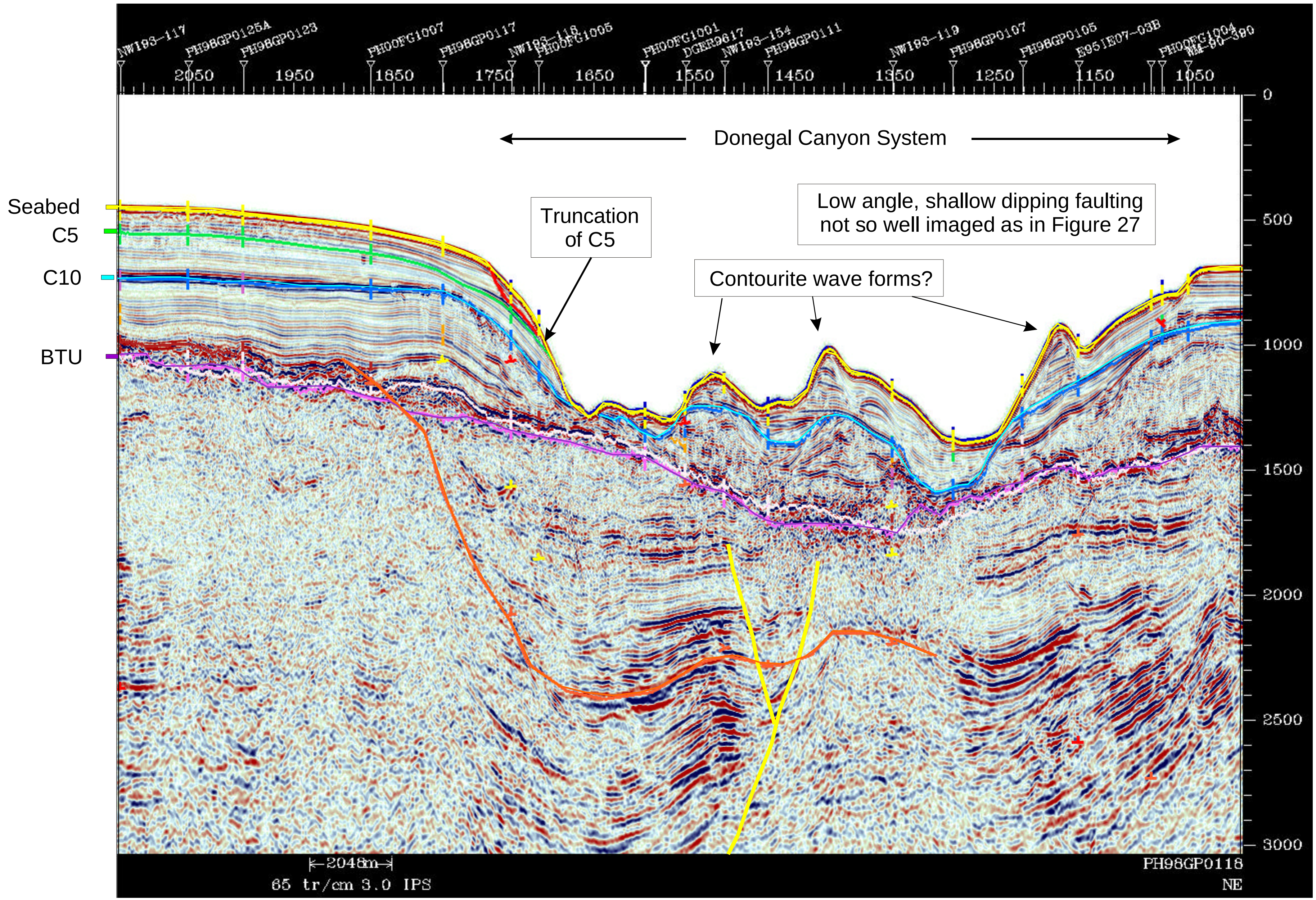


Figure 29

Figure 30

Example of sidewall faulting and older faults in Donegal Canyon.

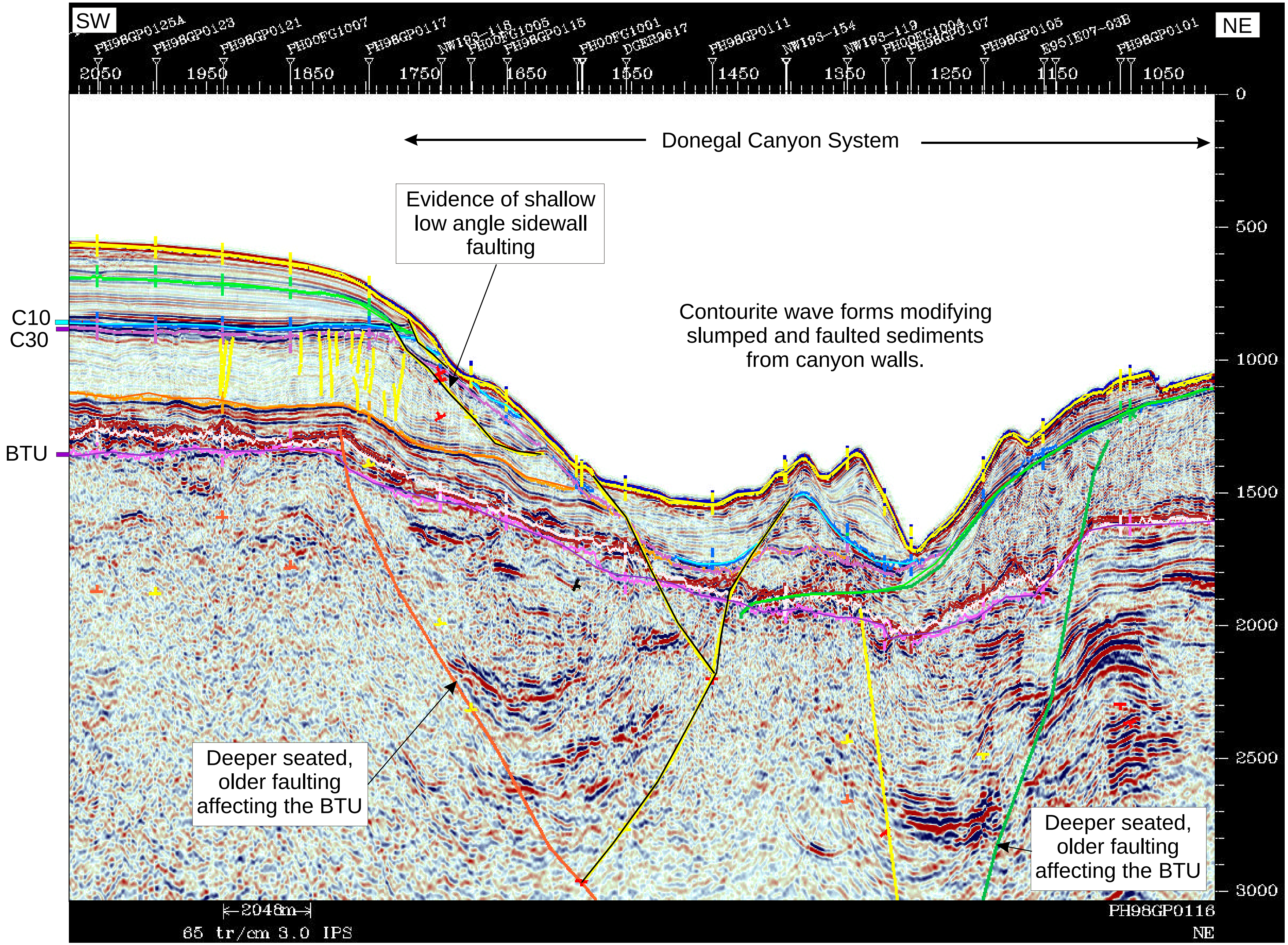


Figure 30

Figure 31 Donegal Canyon increases in breadth downslope.

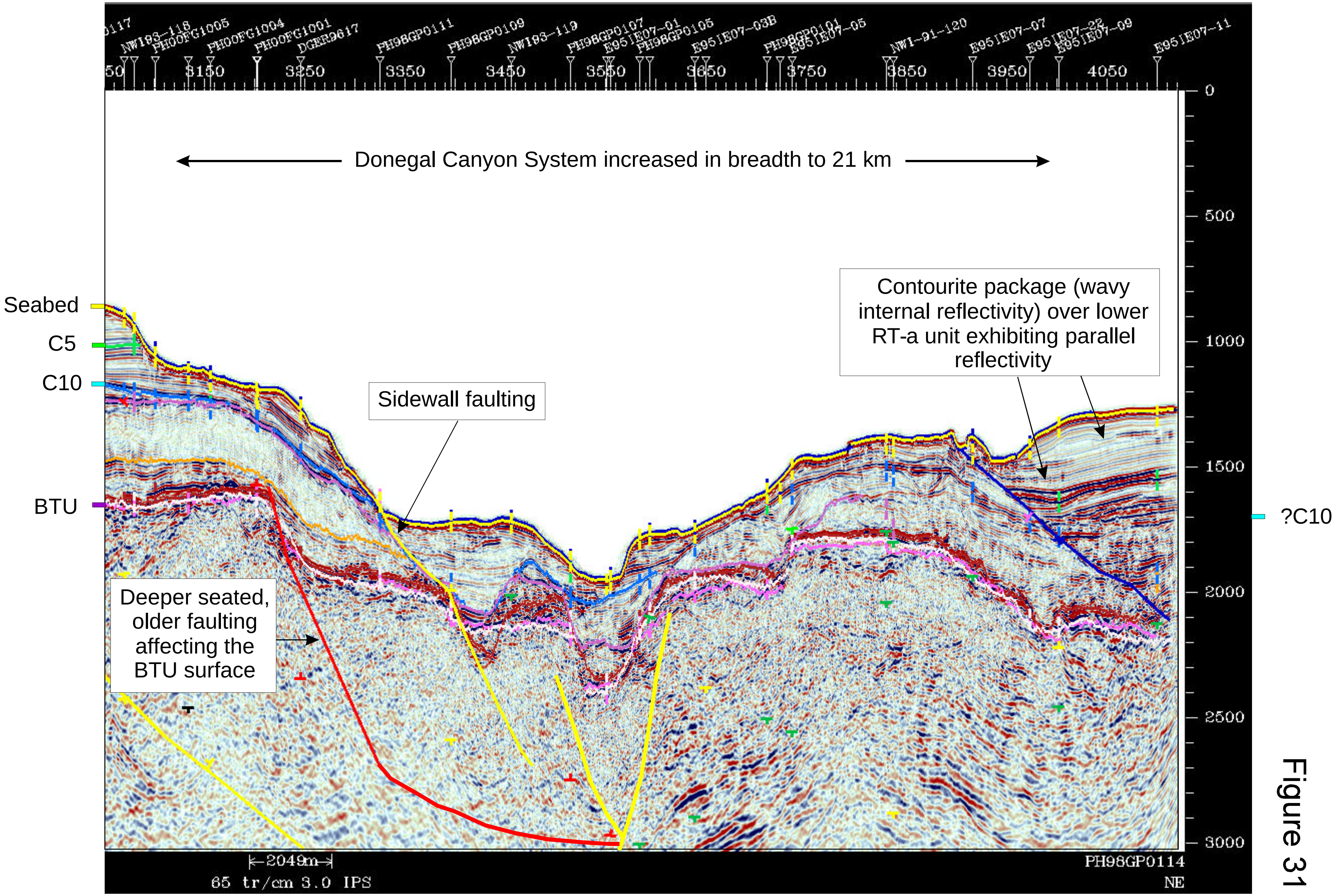


Figure 31

Figure 32

Complex slump and fill sediments in Donegal Canyon.

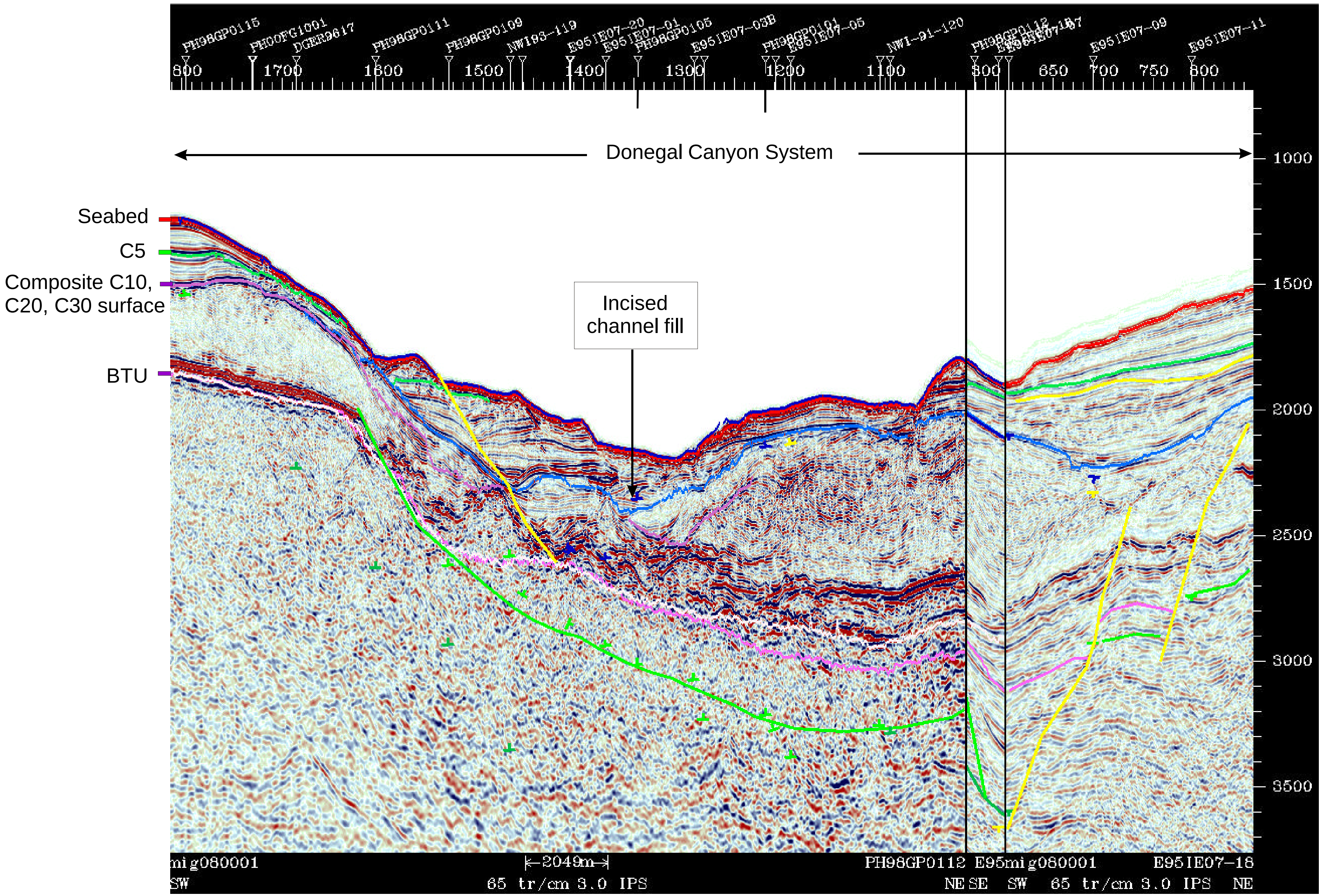


Figure 32

Figure 33 Hummocky bathymetry in lower reaches of Donegal Canyon (lower mid slope setting).

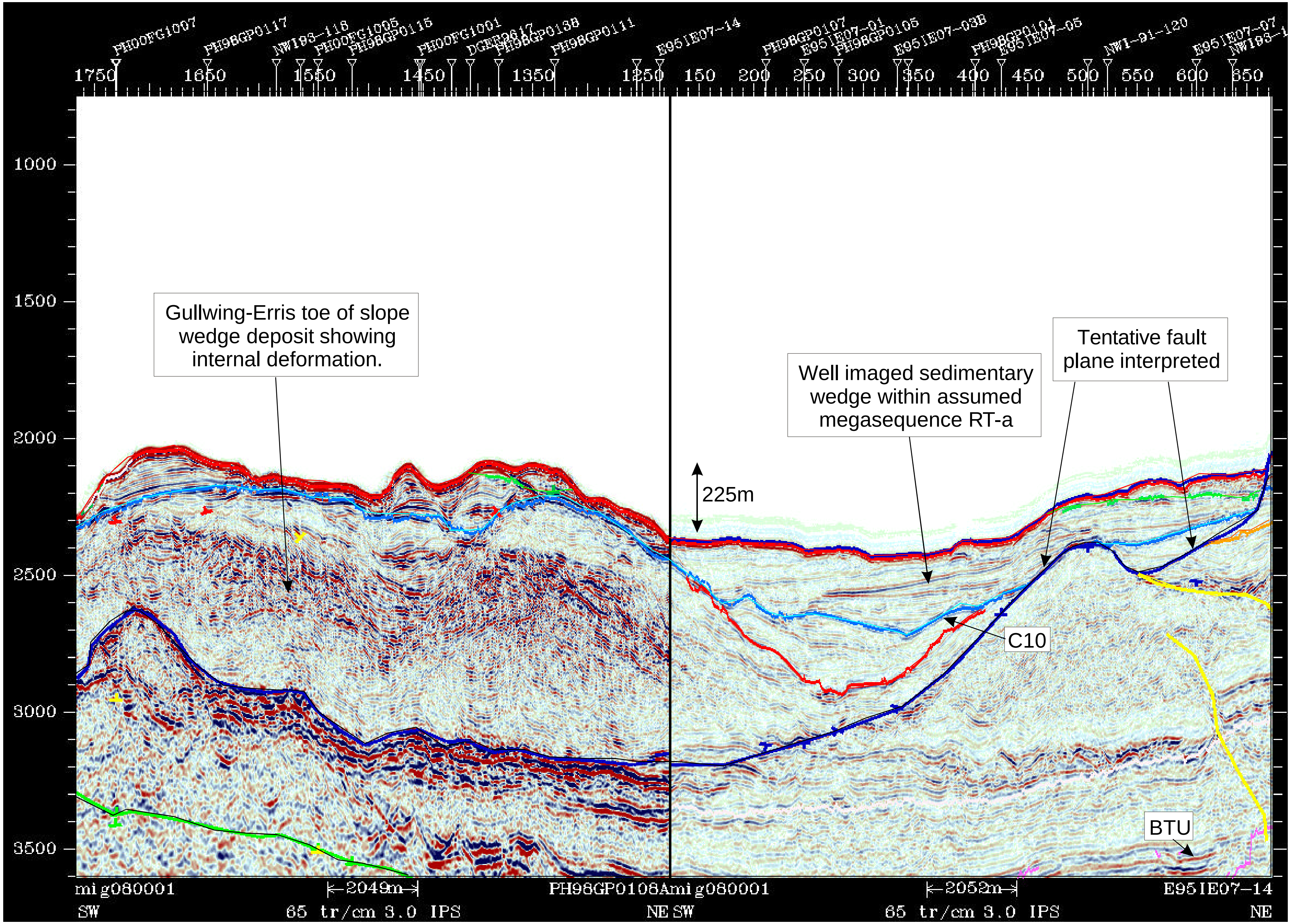


Figure 33

Figure 34

Regional view relating Donegal and TOBI Canyon systems separated by the BH 11/20 slide.

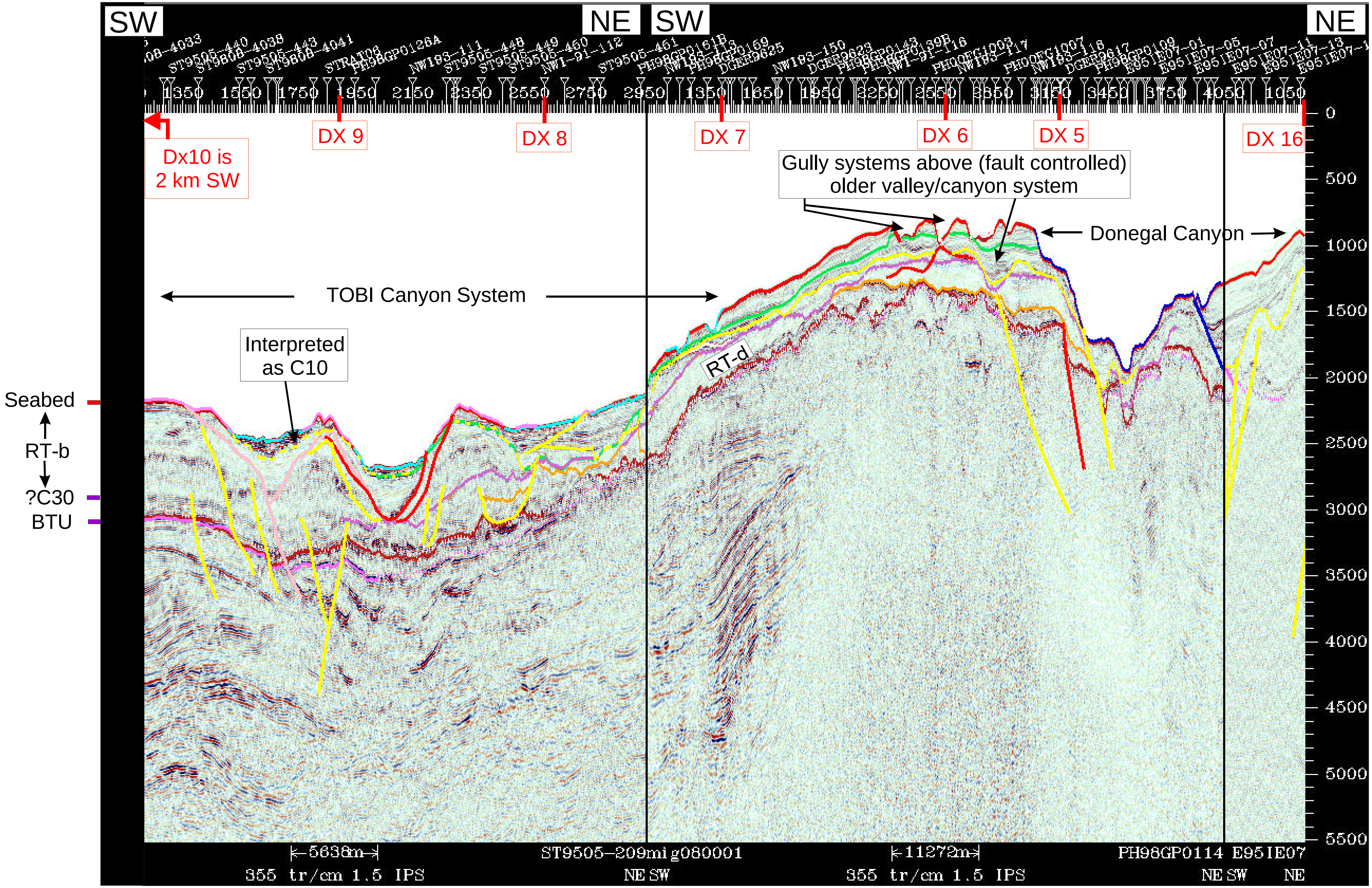


Figure 34

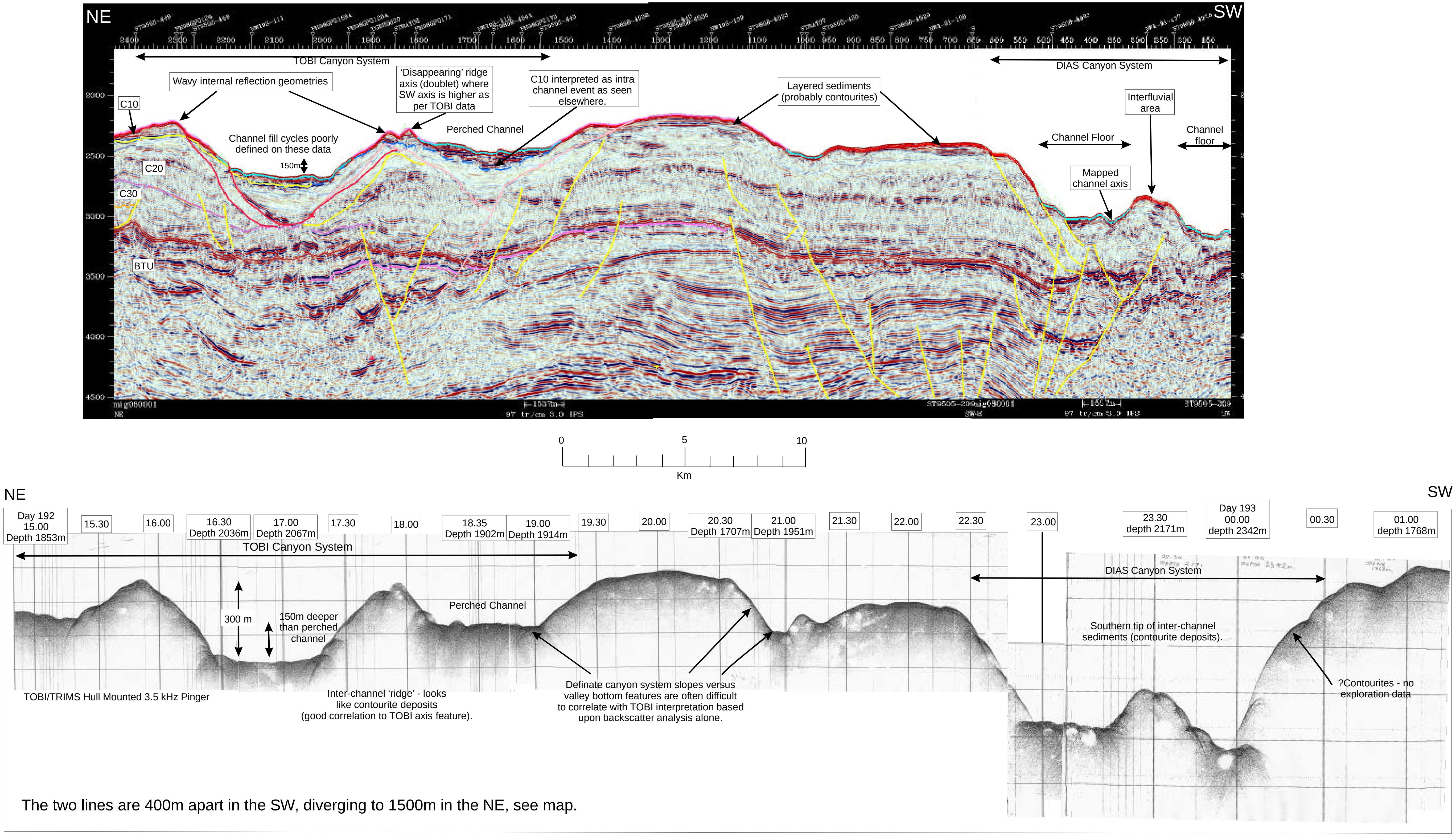


Figure 35 TOBI and DIAS Canyon systems as imaged by 2D exploration seismic and 3.5 kHz data.

Figure 36 Complicated stratigraphic relationships of canyon fill and interpreted coutourite system within the ‘T’ Canyon.

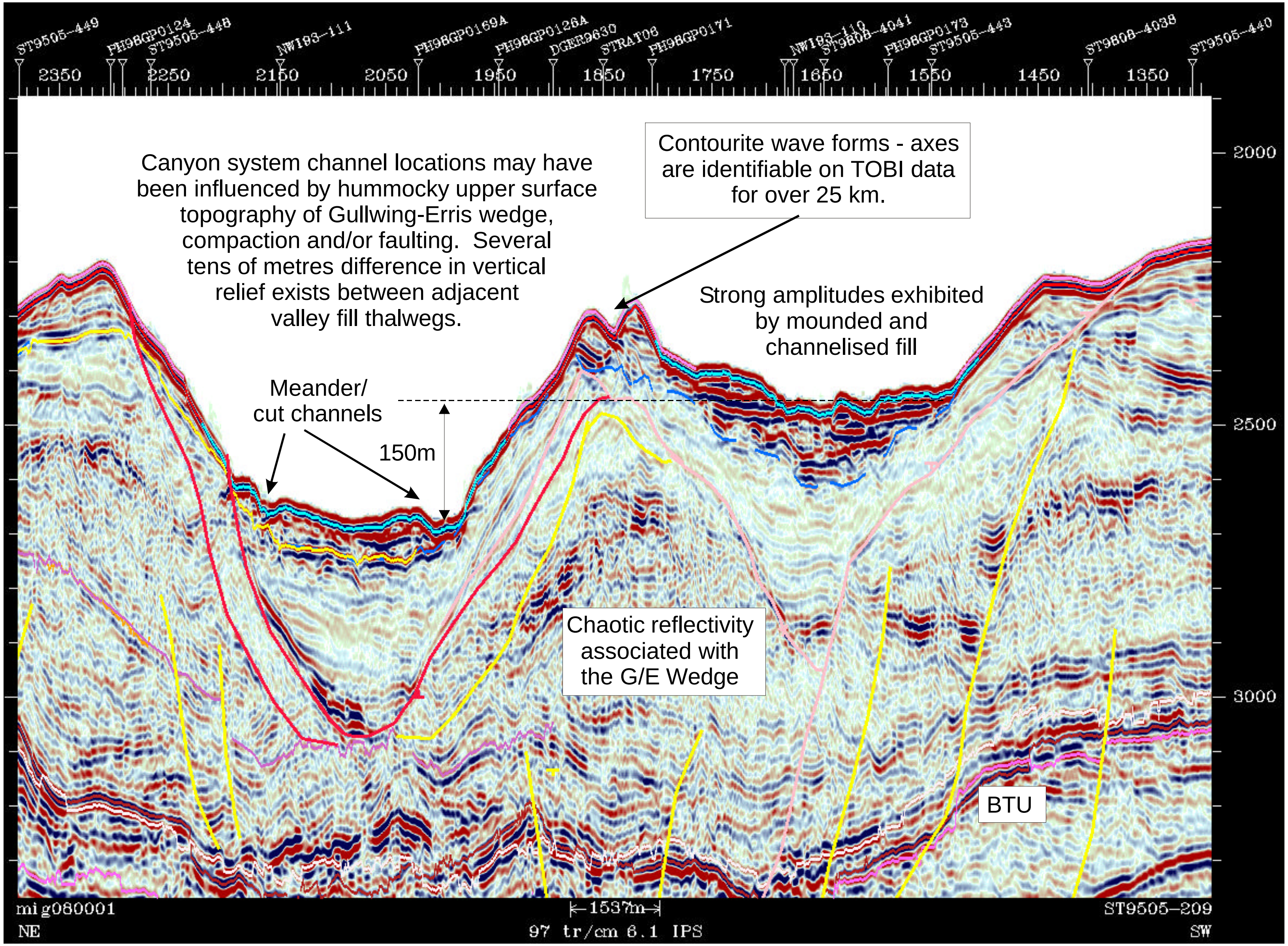


Figure 36

Figure 37

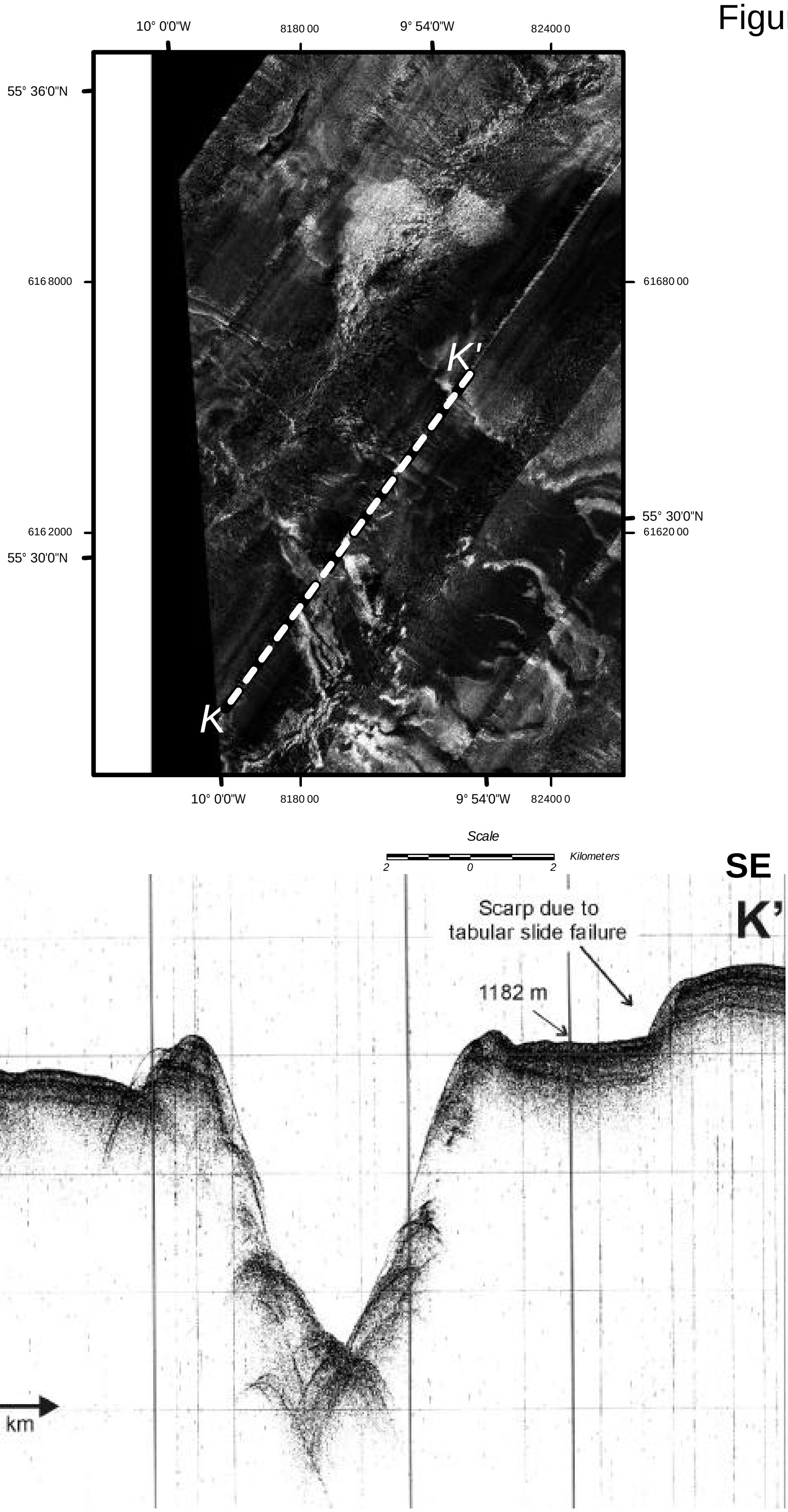
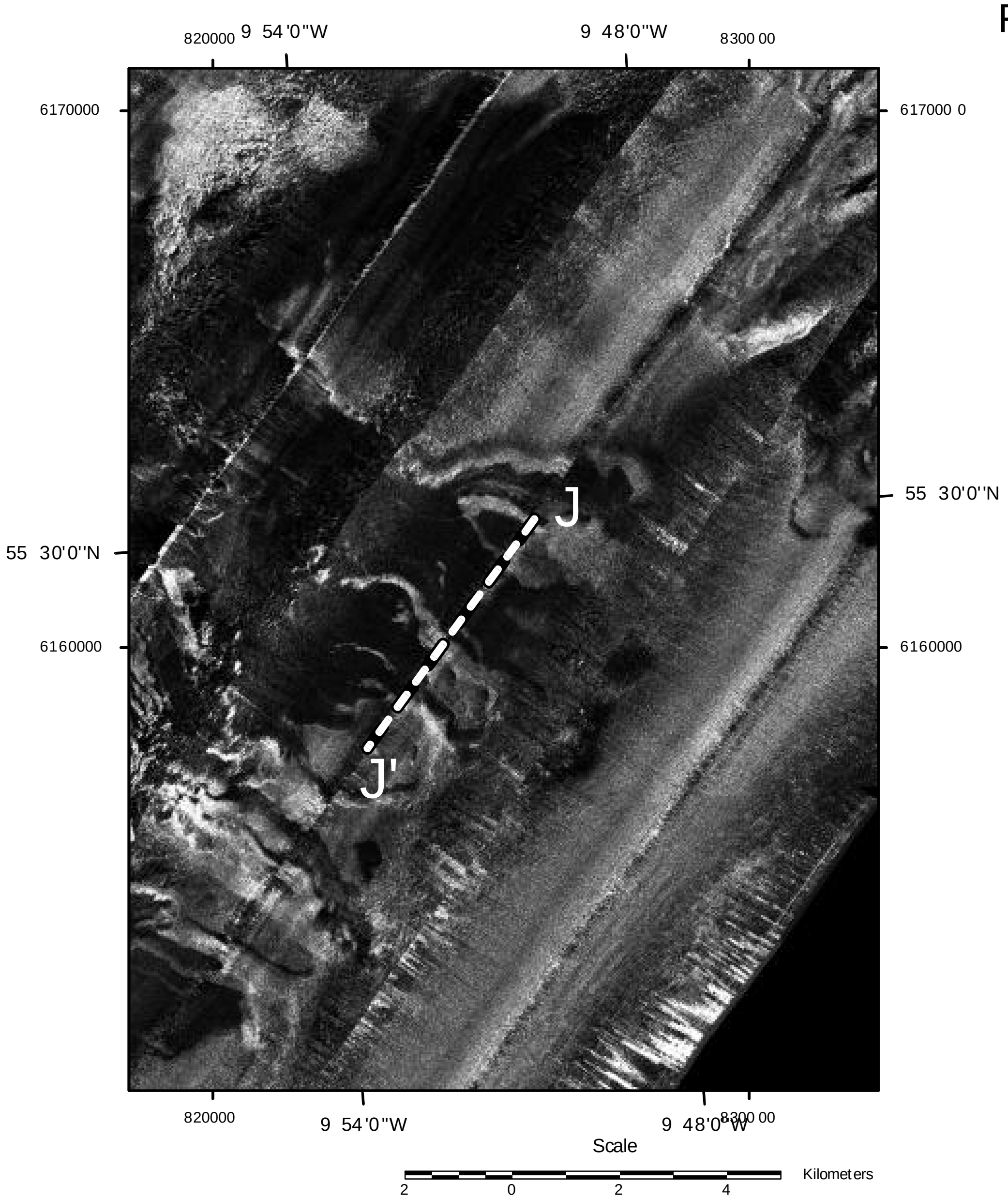


Figure 37 TOBI sonar and 3.5 kHz pinger data example across the V-shaped canyon. Compare with 2D exploration seismic across the same feature in Figure 23. From TRIM Final Report, O'Reilly et al, 2001

Figure 38



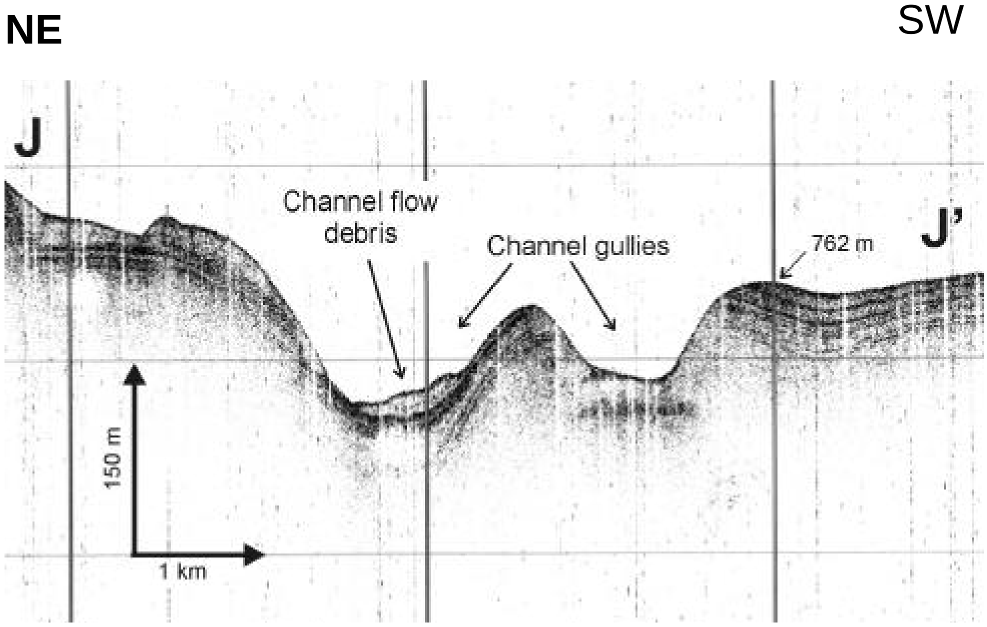


Figure 38 TOBI and 3.5 kHz pinger data example showing surficial channel fill. From TRIM Final Report, O'Reilly et al, 2001.