

## Synthetic-Based Drilling Fluid with Nanoscale Particles Successfully Drills Through Instable and Brittle Formation in Southern Europe

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### Abstract

In a well-known field in Southern Europe, the 2,378-m long intermediate interval is characterized by the overpressured Flysch formation, which is composed of a complex brittle shale. This formation, in offset wells, has created many drilling challenges including the likelihood of wellbore instability due to clay reactivity, tectonic stresses and other mechanisms of mechanical instability. From a drilling management standpoint, this requires a rigorous and tight control of the high density over 16.7 lb/gal while maintaining low filtrate loss to the formation. Key aspects to successfully drill this interval are maintaining the correct fluid density for mechanical wellbore stabilization, tight ECD management while providing adequate hole cleaning to avoid issues with the brittle shale and large washouts. Review of offset wells data, lessons learned from previous projects, and extensive laboratory tests led to an engineered SBDF designed with bridging and sealing package to seal and plug the micro fractures in the wellbore, minimizing fluid pressure propagation into fractures which are responsible for borehole stability issues. A multi-functional nanoscale additive for bridging and sealing, along with graphite, fibers, and different sizes of marble was incorporated into an engineered SBDF which was able to successfully transact the brittle shale. The design and application of these bridging and sealing materials together with optimized well planning and drilling practices resulted in drilling this troublesome formation with a drastic reduction in NPT and reduced overall project cost.

### Introduction

In a complex field in Southern Europe, operators faced wellbore instability problems while drilling through the Flysch formation.

The Flysch shale consists of claystone with siltstone and sandstone stringers. This complex lithology is also associated with development of severe tectonic stress with depth. The stress regime in this field is strike-slip or thrust faulting regime. (Figure 1). This scenario coupled with high in-situ stresses make drilling conditions extremely challenging.



Figure 1: Stress Regime

Generally, this formation is not highly reactive towards water-based muds since the swelling clay content is quite low. Therefore, the problem is not related to chemical shale inhibition but rather to mechanical wellbore stabilization.

There are some driving forces that tend to destabilize and be detrimental for unstable and tectonically stressed formations such as the Flysch shale that shall be address when design a drilling fluid formulation:

- Hydraulic pressure differential caused by pore pressure diffusion/transmission (Stowe et al., 2001)
- Chemical osmosis that is dependent on the difference between the water activity ( $A_w$ ) of the drilling fluid and the shale pore fluid
- When water-based muds are used, there is also a diffusion osmosis that represents the transfer of ions and associated water molecules between the drilling fluid and the shale (Bussaglia et al., 2017).

The following challenges may occur when drilling through this type of unstable formations:

- High borehole instability
- Large washouts
- Excessive cavings
- Difficulty tripping the BHA with high torque and drag, requiring frequent back-reaming
- Hole pack off (with restricted circulation) and stuck pipe events/induced losses
- Hole cleaning problems
- Delamination of the shale due to mud invasion along bedding planes
- Formations that can fracture easily (brittle formation)

This complex environment requires increased planning, testing, and technical recommendations on drilling fluids in order to successfully and safely drill the Flysch shale:

- Use of correct fluid density before encountering the troublesome formation
- If available, make use of geomechanical studies, offset well data and cuttings/cavings observations to predict and control wellbore instability
- Stabilize the borehole walls by limiting mud invasion into fractures and along bedding planes
- Ensure the mud has sufficient carrying capacity to remove cuttings as well as cavings from the hole
- Keep tight filtration rates
- Improve borehole stability with the use of selected bridging/sealing agents. These products can protect the formation by flowing into and sealing micro-fractures that either exist naturally or are created during drilling, thus avoiding the transmission of the pressure of the drilling fluid to the tip of fractures and limiting their growth (pore pressure transmission). The result is a stabilization of the borehole wall, which will reduce the severity of hole instability and enlargement.
- Adjust water phase salinity (either WBM and SBDF) to minimize chemical osmosis.

Borehole instability is not the only issue faced while drilling wells in the present field. In fact, the drilling scenario is exacerbated by other potential problems that make those projects very complex and challenging:

- Presence of aquifer on surface sections that requires the use of environmentally friendly drilling fluid additives
- Possible presence of hard, abrasive chert formation resulting in low rate of penetration and high torque
- Hole cleaning issues while drilling large hole diameter on top hole carbonate sections
- Severe to total losses on top hole fractured carbonate formations
- Overpressure in carbonate reservoir that requires heavy non-damaging reservoir drilling fluids
- Formation losses in carbonate reservoir section
- Potential H<sub>2</sub>S contamination in carbonate reservoir
- Potential presence of overpressure Flysch imbricates in the carbonate reservoir

In this complex drilling environment, the operator requested to improve the performance of the SBDF previously used on recent offset wells in order to minimize wellbore instability while drilling the Flysch formation. After paramount lab work, the fluid team selected a nanoscale material acting as WSM for wellbore stabilization along with a package of bridging materials.

This paper will present an overview of offset experience in same area where wellbore instability was encountered. The SBDF's design with selection of suitable nanoscale additive and bridging materials and final lab test results will also be

discussed. A brief evaluation of the operator's well design to minimize drilling issues will be also addressed. Drilling results and fluid's performance while drilling across the Flysch clay will be then discussed and concluding statements conveyed.

### Offset Wells

The Flysch is a notoriously challenging formation to drill and is prone to bore hole instability and pack-offs, mainly whilst tripping. The majority of offset wells suffered at least one side-track and one well experienced nine sidetracks. The failure comes in many forms with the potential for shear failure, failure whilst drilling parallel to bedding dips and failure due to drilling across formation fractures. Very high in-situ stresses are common in the area.

Four representative offset wells drilled in the same region experienced severe wellbore instability either with HPWBFs or SBDFs when drilling through the the Flysch formation. This particular formation is known to develop tectonic stress with depth and lithology variability.

The wellbore instability has a mechanical origin. Selection of proper mud weight was the first action to take to alleviate the problem although in some wells it was not sufficient to overcome to all those issues deriving from borehole instability. Increasing the mud weight lowered the risk of mechanical breakout, but increased the risk of losses and lubricating microfractures. Fracture-sealing products were also used to prevent fluid's invasion and pressure propagation into the fractures present in the shale with good results in some cases and no real benefits on others.

**Offset Well#01** - The challenging Flysch section from 2,764 to 4,070 m (1,306 m Flysch length) was successfully drilled using an inhibitive HPWBF based on polyalcohols technology. A final MW of 17.1 lb/gal was required to address the wellbore instability. The difficult drilling environment was exacerbated by the presence of reactive clays. (Isinak et al. 2005).

**Offset Well#02** - Despite frequent mechanical stuck pipe incidents caused by a high loading of cavings in the annulus, the Flysch shale formation was drilled from 3,270 to 4,177 m (907 m Flysch length) and hole cased using 14.0 lb/gal SBDF. The operator decided to temporarily abandon the well after encountering Flysch imbricates in the carbonate reservoir section.

**Offset Well#03** - After 7 sidetracks due to pack-offs and stuck pipe incidents (max Flysch length drilled was 1,914 m), the operator decided to temporarily abandon the project due to the impossibility to complete the drilling of the Flysch formation. A 15.9 lb/gal Potassium Silicate water-based fluid was used. Cavings with different shapes were collected on the shakers while drilling the Flysch formation (Figure 2). Tabular cavings (Figure 2a) have a tabular shape and are produced by the fluid's invasion into weak planes/fractures that cause failure along weak bedding planes or cleavages in preexisting fractures. Splintery cavings (Figure 2b) are formed in over-

pressured formations or tectonically stressed zones and their size may range from very tiny splintery pieces to long slivers, several centimeters in length. Angular cavings (Figure 2c) are produced from rock shear failure of the wellbore due to high pore pressure and have an arrowhead or triangular shape with curved faces and rough surface structure (Kumar et al., 2012), (Skea et al. 2018).

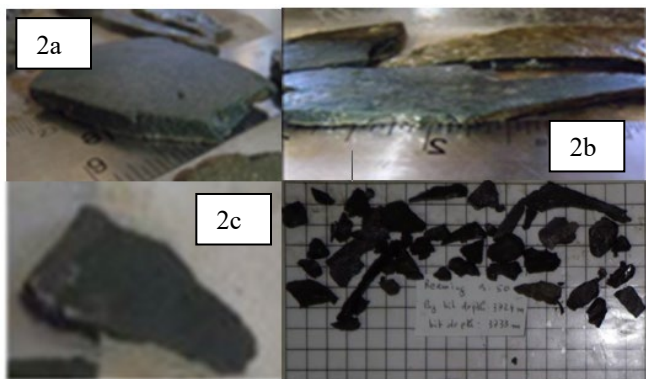


Figure 2: Cavings collected on Offset Well#3: (2a) Tabular, (2b) Splintery, (2c), Angular

**Offset Well#04** - This formation was successfully drilled from 3,422 m to 4,927 m (1,505 m Flysch length) with 16.5 lb/gal SBDF using a blend of bridging agent and polymeric sealing agents to prevent fluid invasion into formation.

Bulk and clay composition of Flysch cuttings taken from Offset Well#01, Offset Well#02 and Offset Well#04 are showed respectively in Figure 3 and Figure 4 respectively confirming variability of lithology from well to well. Offset well #01 was drilled with a WBM therefore the cuttings sample integrity could be compromised during collection and analysis.

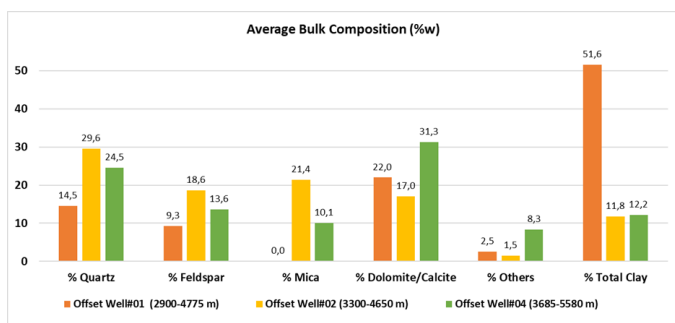


Figure 3: Bulk composition

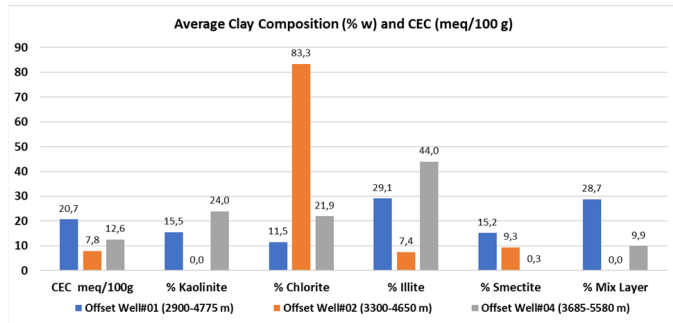


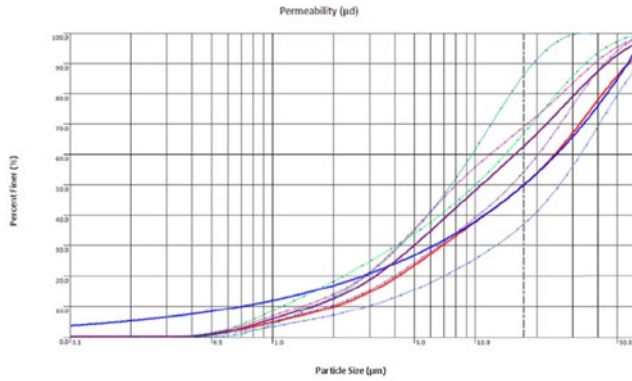
Figure 4: Clay composition SBDF Design with Nano Particles Additive

As part of drilling fluid's improvement process, the following benchmarks were established during the design of SBDF:

- Use correct mud weight while penetrating the unstable formations from a minimum of 16.7 lb/gal in the upper part of Flysch to a max of 19.2 ppg in the lower part above the carbonate reservoir
- Run a high Oil/Water ratio ranging from 90/10 to 95/5 in order to minimize Plastic Viscosities and lower fluid's rheology due to high solids content required to keep heavy mud weights
- Obtain a very low absolute HTHP filtrates 186° F/500 PSI < 1 ml/30 min with thin filter cake thickness using 5 µm aloxite disk as filter media corresponding to the expected microfractures
- Provide an adequate fluid rheology profile for optimum hole cleaning even in the case of a high cavings load in the annulus as a consequence of wellbore instability
- Use a package of bridging, sealing and wellbore strengthening materials for wellbore stabilization and sealing of microfractures

The SBDF was formulated to address the above required specifications with the following key additives:

- Primary and Secondary emulsifiers were selected to stabilize the emulsion
- 10.2 lb/gal CaCl<sub>2</sub> was used to control the water phase salinity
- High Yield Organoclay together with a Polymeric Rheology Modifier were chosen to provide adequate fluid rheology at low concentration
- Wetting agent was introduced to improve the oil wettability of solids
- Combination of liquid filtration reducer additive and polymeric material were selected to control fluid loss
- A blend of sized marble calcium carbonate and natural graphite were used for optimum bridging. The bridging materials were selected and optimized by running a proprietary software to confirm proper bridging properties on 5-micron formation (Figure 5).



**Figure 5: Outcome from bridging package design**

- After extensive lab testing where different type of nanomaterials such as dry spray latex, vinyl acetate/ethylene copolymer powder, natural materials, and nano talco additive were carefully evaluated, the SBDF was formulated with the use of a metal oxide nanomaterial suspended in a hydrocarbon carrier acting as WSM
- One of the benefits of the nanomaterial chosen was it did not negatively impact the OWR or rheology properties of the SBDF
- Barite was used as weighting agent.

Final SBDF formulations selected to be used at the field are showed on [Table 1](#).

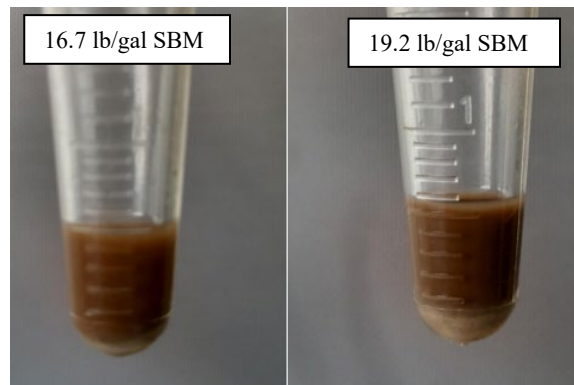
**Table 1: SBDF Formulation**

Product	16.7 lb/gal	19.2 lb/gal
Mineral Oil	0.56 bbl	0.48 bbl
Primary Emulsifier	5.3	5.3
Secondary Emulsifier	5.3	5.3
Hydrated Lime	7.0	7.0
10.2 lb/gal CaCl <sub>2</sub> brine	0.025 bbl	0.021 bbl
High Yielding Organoclay	6.3	2.1
Polymeric Rheology Modifiers	0.7	0.7
Wetting Agent	0.7	0.7
Liquid Fluid Loss Reducer	5.3	5.3
Polymeric Fluid Loss Reducer	1.0	1.0
Sized Graphite Bridging agent	5.3	5.3
Sized Marble Carbonate Bridging agent	10.5	10.5
Nanomaterial WSM	1.0	1.0
Barite	492.3	624.2

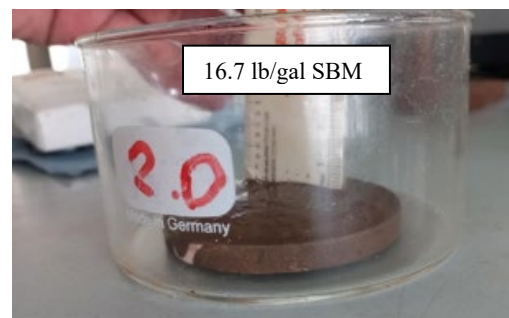
Lab testing results AHR at 187 °F for 16 hours can be seen in [Table 2](#). Both fluids show an optimized rheology profile and outstanding absolute fluid loss through the 5 µm aloxite disk ([Figure 6](#)) with a thin and homogeneous filtercake ([Figure 7](#) and [Figure 8](#)).

**Table 2: SBDF Properties**

Properties	Unit	16.7 lb/gal		19.2 lb/gal	
Rheology Temp.	°F	129	150	129	150
600 rpm	lb/100ft <sup>2</sup>	148	137	164	134
300 rpm	lb/100ft <sup>2</sup>	87	77	94	75
200 rpm	lb/100ft <sup>2</sup>	67	57	67	54
100 rpm	lb/100ft <sup>2</sup>	42	36	42	33
6 rpm	lb/100ft <sup>2</sup>	13	11	11	10
3 rpm	lb/100ft <sup>2</sup>	11	10	9	8
Plastic Viscosity	cP	61	60	70	59
Yield Point	lb/100ft <sup>2</sup>	26	17	24	16
Gels (10 sec.)	lb/100ft <sup>2</sup>	11	10	9	8
Gels (10 min.)	lb/100ft <sup>2</sup>	20	15	22	19
Electrical Stability	Volt	1592	1580	1560	1492
Oil/Water	-	95/5		95/5	
Absolute HTHP Filtrate (186° F/5 µm aloxite disk)					
1 min.	ml	0.0	0.0	0.0	0.0
10 min.	ml	0.2	0.2	0.2	0.2
30 min.	ml	0.5	0.5	0.5	0.5
Filter cake thickness	1/32"	2.0	2.0	2.0	2.0



**Figure 6: SBDF Absolute Fluid Loss volume**



**Figure 7: 16.7 lb/gal SBDF Filter cake on disc**

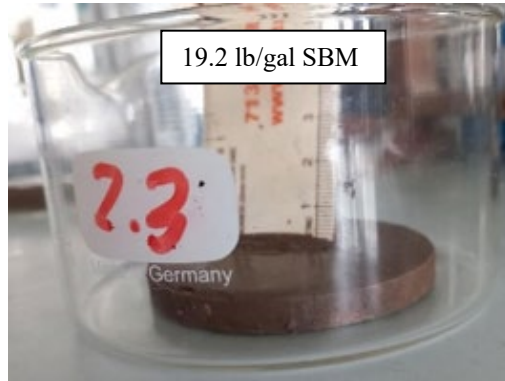


Figure 8: 19.2 lb/gal SBDF Filter cake on disc

### Well Design

Due to the very long planned Flysch interval (2,378 m) to be drilled compared to the offset wells (minimum Flysch length of 907 m to a max of max 1,505 m), in order to minimize drilling risks and borehole instability failure, the operator decided to modify the well design and drill this troublesome formation in two separate sections instead of drilling one single interval as done on offset wells:

- 17 1/2" hole from 1,924 m to 3,500 m with 16.7 lb/gal SBDF
- 12 1/4" hole from 3,500 m to 4,302 m with 19.2 lb/gal SBDF

In addition to fluid's optimization, a new drilling strategy was also adopted to improve drilling practices, optimize annular clearance and ensure stabilization on all BHA designs.

See Figure 9 for schematic.

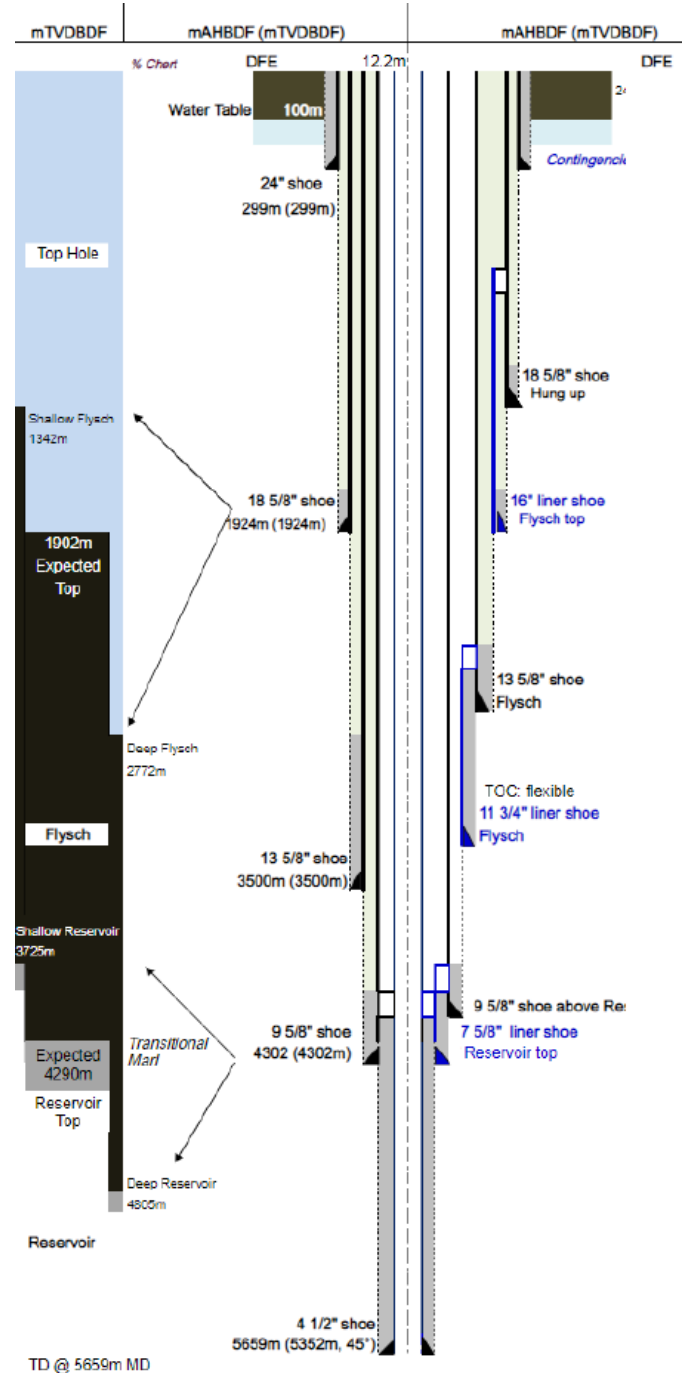


Figure 9: Well Design

### Drilling Results

The shallow carbonate interval above the Flysch was significantly longer than expected. The Flysch formation was in fact found at 2,740 m instead of 1,924 m.

Before spudding the Flysch sections, the project team reviewed experiences and lessons learned on previous projects. The drilling team implemented improved drilling practices such as tripping out, tripping in, controlled penetration rates,

optimization of BHA design and dedicated mitigations against stuck pipes incidents which could have occurred due to wellbore instability.

Dedicated tripping procedures and controlled penetration rates were adopted to minimize the risk of pack-offs due to an accumulation of cuttings in the annulus. The build up of cuttings could have been generated while drilling or falling of cuttings/cavings in the form of round bit/stabs from large washouts. Limiting the tripping velocity and minimize excessive surge/swab pressures with the BHA inside the casing were also employed as best practices.

The pack-off stuck pipe mitigations were mainly focused to reduce high pressure spikes while trying to reestablishing circulation to prevent formation breakdown whenever possible.

A brief recap of drilling operations related to the 17 1/2" and 12 1/4" sections through Flysch formation where the engineered SBDF was deployed is summarized hereafter.

### **17 1/2" Hole from 2,740 m to 3,450 m**

Prior to the start of drilling the upper part of the Flysch in 17 1/2", a 13.4 lb/gal SBDF was mixed at the LMP in accordance with the fluid design comprising of the Sized Marble and Graphite bridging package and Nanoparticle sealing additive. Once on location, the SBDF was weighted up to 16.7 lb/gal and drilling commenced

Total losses were recorded at the depth of 2,958 m when drilling through a fractured fault composed of limestone with calcite and traces of reddish-brown Marl and an increase of background gas was observed on surface. Losses eventually healed and once fluid returned at the shakers, 10% v/v cavings were reported. The composition of the cavings was mainly angular shape and a minor quantity of tabular cavings with a maximum length of 6 cm.

Drilling continued to section TD at 3,450 m where losses were encountered again in the above fault zone with initial loss rate of 10 bph increasing to total losses. In accordance with the engineered losses decision tree, three LCM pills of varying products and concentrations were pumped downhole without success. Static losses were finally cured by reducing mud weight from 16.7 lb/gal to 16.1 lb/gal.

During RIH with the 13 5/8" casing, downhole losses continued with an average loss rate of 6 bph. The casing was successfully set on bottom and safely cemented.

Drilling was completed in 4 days without facing any significant issues related to wellbore instability.

The Flysch lithology was quite consistent throughout the interval mainly composed by 50-70% Claystone, 30-40% Siltstone and traces up to 20% Sandstone.

### **12 1/4" Hole from 3,450 to 4,952 m**

Before commencing drilling the deeper Flysch interval, the mud weight was raised up from 16.1 lb/gal to 16.7 lb/gal. The section was drilled with 16.7 lb/gal SBDF to TD at 4,952 m with same BHA, without performing any tripping out and any further increase of mud weight. In fact, there was not the

operational need of increasing the MW to 19.2 lb/gal as per drilling program since the 16.7 lb/gal was sufficient to ensure proper mechanical wellbore stabilization.

Even though the deeper Flysch section was drilled without any issues related to wellbore instability, during POOH, severe overpulls up to 30 klb were registered that required the application of customized pulling out practices consisting of low pipe rotation and low flow rates while performing back reaming operations. Minor downhole losses were also recorded during pull out operations. The proper applied procedures allowed the drilling team to pull the bit out of the hole in four days.

The 9 5/8" casing string was run as planned to 1,800 m and then smoothly lowered to section TD without facing any drag and torque related issues. The cement job was successfully and safely performed to secure the Flysch interval above the carbonate reservoir section.

On this second Flysch interval, the rock's characteristics remained almost the same as the previous interval (no need to increase MW to 19.2 lb/gal) although a slightly increase of shale content was detected.

### **Drilling Fluids Performances**

The engineered SBDF coupled with optimized drilling practices, allowed the drilling of the Flysch formations without any stuck pipe events with very limited Non-Productive Time (few hours only). The NPT was attributed to back reaming operations in the 12 1/4" section.

The correct mud weight represented the first line of defense in controlling borehole instability in such overstressed, brittle and unstable formations. It was proven that drilling such kind of formations with the right mud weight highly contributed to minimize formation instability. In this specific project, 16.7 ppg was the correct mud weight to mechanically stabilize the wellbore without any further increases to 19.2 lb/gal in the deeper Flysch interval as anticipated in the drilling program.

The 17 1/2" hole remained stable not only while drilling but even when fluid density was reduced from 16.7 lb/gal to 16.1 lb/gal to reduce fluid's pressure on bottom in order to address formation losses. The 16.7 lb/gal mud weight was then re-established and maintained throughout drilling the 12 1/4" to section TD.

While drilling, the solid control equipment package consisting of shale shakers and three decanting centrifuges were properly set up and run. This ensured to maintain stable mud weight by minimizing a detrimental loading of drill solids into the mud. In addition to stabilizing the density, this also ensured a consistent rheology profile of the SBDF.

Solids control equipment coupled with proper fluid's dilution rates allowed to keep a max concentration of drill solids in the drilling fluid below 7% v/v throughout the Flysch intervals.

The heavy mud weight required an Oil/Water ratio at 91/9 to minimize plastic viscosities and avoid elevated rheological properties. The water phase salinity was controlled with the use of CaCl<sub>2</sub> salt to minimize osmotic pressures thus improving

chemical wellbore stabilization.

A high yielding organoclay together with polymeric rheology modifier was used to optimize fluid's rheology while minimizing solid content.

A tight HPHT fluid loss was important to minimize filtrate invasion. Fluid loss values on a 5- $\mu\text{m}$  aloxite disk were maintained below 3.5 ml/30 min (186° F/500psi) using proper fluid loss reducers and the customized bridging package composed of calcium carbonate marble materials and sized graphite.

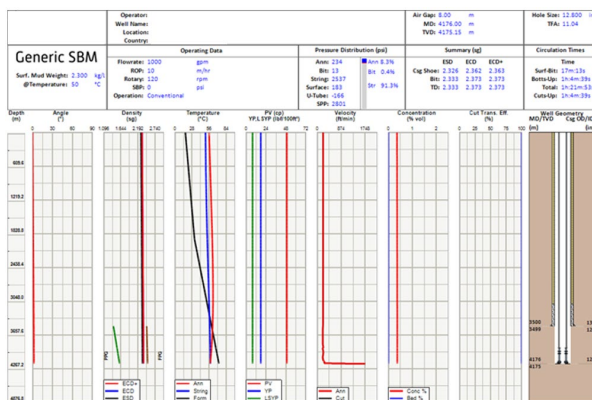
A nanoparticle liquid WSM helped to efficiently stabilize the wellbore by sealing and plugging natural microfractures present in Flysch shales thus minimizing fluid's pressure propagation into formation.

The average SBDF's properties of each Flysch section can be seen on [Table 3](#).

**Table 3: Average SBDF properties of each Flysch section**

Properties	Unit	17 ½" Hole	12 ¼" Hole
MW	lb/gal	16.1-16.8	16.1-16.8
Funnel Vis.	sec/liter	50-77	55-124
Rheology Temp.	°F	150	150
Plastic Viscosity	cP	21-39	19-81
Yield Point	lb/100ft <sup>2</sup>	13-24	8-30
Gels (10 sec.)	lb/100ft <sup>2</sup>	7-14	5-16
Gels (10 min.)	lb/100ft <sup>2</sup>	8-22	10-29
Gels (30 min.)	lb/100ft <sup>2</sup>	12-30	12-33
Electrical Stab.	Volt	564-1032	531-1419
Oil/Water	-	81/19-91/9	85/15-91/9
Lime Excess	ppb	2.85-3.9	1.85-3.4
P <sub>om</sub>	ml H <sub>2</sub> SO <sub>4</sub>	2.2-3.0	0.5-2.6
WPS (as CaCl <sub>2</sub> )	ppm	199,000-301,554	247,143-345,545
Absolute HTHP Filtrate (186° F/5 $\mu\text{m}$ aloxite disk)			
30 min.	ml	1.4-3.5	0.7-3.4

Hole cleaning efficiency and hydraulics parameters were monitored daily by running a proprietary software simulator ([Figure 10](#)). The program was used to predict fluids behavior downhole and minimize risks for the drilling operations.



**Figure 10: Outcome from Hydraulic Software Simulator**

## Liquid Mud Plant Management and Logistic

Best in class LMPs ([J. Huggins et al. 2017](#)) ([Bussaglia et al. 2018](#)) were designed and installed in the proximity of the well site to improve project efficiency and economics in a safe and compliant manner.

A dedicated LMP was installed nearby the well location for mixing and storage of the SBDF.

A total volume of 7,290 bbl of 13.4 lb/gal SBDF was mixed at the LMP and transferred to the rigsite. Once on location, it was weighted up with Barite to 16.7 lb/gal and stored inside the rig's tanks. Once both Flysch sections were completed and cased, the fluid was centrifuged and 2,660 bbl of 12.5 lb/gal SBDF was sent back to and properly stored in dedicated tanks of the LMP.

A second LMP was set up close to the rig site designed for mixing and storing WBM RDF for the reservoir section after drilling the Flysch formation. 9,560 bbl RDF WBM at 11.9 lb/gal were mixed and delivered to the rig site. After the reservoir section was completed, 3,088 bbl RDF WBM was sent back to the LMP and 3,239 bbl was transferred into 1 m<sup>3</sup> IBC containers.

The SBDF and RDF WBM volumes were transported to and from the rig using liquid bulk delivery trucks.

In addition to the two LMPs, a smaller portable LMP was installed on the well location to facilitate displacement operations and optimize overall fluid volumes management without interrupting rig operations. The design and capacity of each LMP utilized on this project are showed on [Table 4](#), [Table 5](#) and [Table 6](#).

**Table 4: SBDF LMP Design and Capacity**

SBDF LMP Design	Capacity (bbl)
Mixing Tank #1	440.3
Mixing Tank #2	440.3
Storage Tank #3	440.3
Storage Tank #4	440.3
Storage Tank #5	440.3
Storage Tank #6	440.3
Storage Tank #7	440.3
Storage Tank #8	440.3
Storage Tank #9	440.3
Storage Tank #10	440.3
<b>Total Volume</b>	<b>4,403</b>

**Table 5: WBM LMP Design and Capacity**

WBM LMP Design	Capacity (bbl)
Mixing Tank #1	453.2
Mixing Tank #2	451.3
Storage Tank #3	406.8
Storage Tank #4	406.8
Storage Tank #5	406.8
Storage Tank #6	406.8

Storage Tank #7	406.8
Storage Tank #8	406.8
<b>Total Volume</b>	<b>3,345.3</b>

**Table 6: Portable LMP Design and Capacity**

Portable LMP Design	Capacity (bbl)
Mixing Tank #1	440.3
Storage Tank #2	440.3
Storage Tank #3	440.3
<b>Total Volume</b>	<b>1,290.9</b>

Figure 11 and Figure 12 show respectively the SBDF LMP and WBM LMP.



**Figure 11: SBDF LMP**



**Figure 12: WBM LMP**

## Conclusions

This paper describes the successful application of an engineered SBDF to drill over pressurized and unstable Flysch formations in an on-land well in southern Europe.

After extensive lab testing, the fluid team decided to use a nanomaterial additive and bridging materials package that, together with correct mud density, highly contributed to stabilizing the wellbore, thus minimizing NPT and avoiding

costly sidetracks as experienced on previous projects in the area.

The new well design consisting of drilling of the Flysch formation in two distinct sections and application of engineered drilling practices and procedures, also contributed to the success of this project.

To manage large volumes of fluids required, two dedicated LMPs and a portable LMP were utilized to mix and store fluids.

The successful application of this SBDF is a useful example of what can be accomplished in similar situations in the future.

## Acknowledgements

The authors wish to thank Shell and Newpark for permission to present this paper. Special thanks to the Newpark fluid coordinators field and liquid mud plants personnel, for their excellent performance and support.

## Nomenclature

<i>AHR</i>	<i>After Hot Rolling</i>
$\mu\text{m}$	<i>micrometer</i>
<i>bbl</i>	<i>Barrel</i>
<i>BHA</i>	<i>Bottom hole assembly</i>
<i>bph</i>	<i>Barrel per hour</i>
<i>cP</i>	<i>Centipoise</i>
<i>ECD</i>	<i>Equivalent Circulation Density</i>
<i>F</i>	<i>Fahrenheit</i>
<i>HPHT</i>	<i>High Pressure, High Temperature</i>
<i>HPWBF</i>	<i>High Performance Water Base Fluid</i>
<i>klb</i>	<i>1000 Pound</i>
<i>lb/100ft<sup>2</sup></i>	<i>Pound per hundred square feet</i>
<i>lb/gal</i>	<i>Density, Pound per gallon</i>
<i>LCM</i>	<i>Lost Circulation Material</i>
<i>LMP</i>	<i>Liquid Mud Plant</i>
<i>m</i>	<i>Meter</i>
<i>ml</i>	<i>Milliliter</i>
<i>MW</i>	<i>Mud Weigh</i>
<i>NPT</i>	<i>Non-Productive Time</i>
<i>POOH</i>	<i>Pool out of Hole</i>
<i>ppb</i>	<i>Pounds per barrel</i>
<i>ppm</i>	<i>Part per million</i>
<i>PSI</i>	<i>Pound per square inch</i>
<i>RDF</i>	<i>Reservoir drilling fluid</i>
<i>RIH</i>	<i>Run in Hole</i>
<i>rpm</i>	<i>Revolutions per minute</i>
<i>SBDF</i>	<i>Synthetic-based drilling fluid</i>
<i>TD</i>	<i>Total Depth</i>
<i>WBM</i>	<i>Water-based drilling fluid</i>
<i>WSM</i>	<i>Wellbore strengthening material</i>

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