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How to Maintain Wellbore Stability In Deepwater Non-Consolidated Productive Sands By Using Calcium Carbonate Flakes in Water-Based Drilling Fluid

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Abstract

The use of granular calcium carbonate as a bridging and sealing agent is a generally accepted practice in the industry to aid in wellbore stability and preventing damage in permeable formations. However, the use of calcium carbonate flakes to prevent severe mud losses while drilling sands of high permeability is a recent innovation. The calcium carbonate flakes have unique properties due their size and shape, similar to synthetic graphite in preventing fracture propagation.

Maintaining borehole integrity in the Oligocene sands was the primary objective while drilling a series of wells in the Espirito Santo Basin in Brazil. However, wellbore problems continued and attempts to solve this problem with the use of oil-based mud were unsuccessful. Despite enlarged hole conditions, limited core was obtained and evaluated, demonstrating the presence of highly unconsolidated sands in the potential production formation. Analysis and interpretation of this core sample was used as the basis for a new drilling fluid design.

The use of a novel fluid design combining granular and flakes of calcium carbonate reduced the hole enlargement from 30-50% in the previous wells to 4%. By using this fluid, it was not possible to confirm the presence of potential hydrocarbons due to minimum hole enlargement which hindered the collection of core samples in previous wells and led to a sub-optimal evaluation of the reservoir. The use of granular calcium carbonate in combination with two different sizes of flaked calcium carbonate minimized hole enlargement while drilling unconsolidated sands containing hydrocarbons.

This paper discusses this new approach to preventing hole enlargement in shallow unconsolidated sands containing hydrocarbons in deepwater operations. This application is considered to be important due to the challenges of deepwater exploration in the near future.

Introduction

Hole instability in unconsolidated formations is due to the action of in-situ stresses, physio-chemical effect of poor drilling muds or a combination of them. The presence of weak, unconsolidated an friable sand formations in some oil and gas fields creates borehole problems due to sand erosion, borehole washout, sand collapse and induced fracturing. Unconsolidated and friable sand formations have no or poor inter-particle cementation and cohesive forces to hold sand particles together. For this reason, the forces causing failure, e.g., hydro-mechanical disturbance and in-situ stress change, easily exceed the resistance offered by the sand matrix. Strengthening of the matrix of such weak formations by chemicals, polymers, or a combination of both is expected to reduce the scope of failure of the formations due to the formation of adequate cementation, inter-particle cohesion or the combining of both. This allows the drilling of weakly consolidated, low-strenghth, and troublesome formations

In deepwater wells, unconsolidated formations below the sea bed are weekly bonded with little cementation and inter-particle cohesion forces due to a significantly lower overburden effect of water column compared to the effect of equivalent rock column. Hence, these formations are prone to failure by mechanical disturbance and in-situ stress change due to a narrow mud weight window leading to severe wellbore instability problems while drilling. The limited range of mud density control in deep water drilling due to a narrow mud weight window, defined by the collapse pressure and fracture pressure gradients, makes the deep water drilling more complex and troublesome. The loose and friable sand formations create frequent borehole problems due to erosion, borehole washout, sand collapse and lost circulation, primarily due to poor mechanical properties. This also makes them vulnerable to in-situ stress effect and hydraulic disturbance arising due to mud flow, drill string rotation and working while making a trip. According Muller[1] borehole instability is very common in deep water basins due to the presence of poorly consolidated sand layers below the sea bed. The poorly consolidated interval can be extended up to 2,000 ft downward from the bottom of the sea bed and thus can force the setting of unplanned casing strings to isolate the zone. Hence the elimination of the borehole instability problems associated with the weak and unconsolidated sand formations by inducing formation stabilization while drilling could be an effective method of reducing cost in deep water wells. According to Cowan[1], drilling hazards such as lost circulation, well control, isolation of weak formations can be successfully controlled by inducing hole stabilization while drilling.

This paper presents the use of one of those techniques of “well bore strengthening” for minimizing hole enlargement in deep water and evaluating the potential of heavy hydrocarbons in loose sands.

Formation Strengthening Mechanisms[1]

Different methods are used to improve strength properties of near wellbore formation. These methods can act alone or in combination:

Formation of Compressive Stress Cage. In this method, an optimum mud weight is used to create tiny fractures or slightly open existing fractures with immediate bridging of the fracture mouth with suitable particles to apply compressive force in the borehole wall by the mechanical support of the bridging materials. Aston[2] et al. demonstrated the effectiveness of designer mud in creating stress cage to improve fracture gradient in the USA and North Sea. Ramirez[3] et al. also reported successes in the Cusiana field of Colombia.

Sealing and Inter-Particle Bonding. Sealing of porous and permeable matrix of high permeable and fractured formations by suitable chemicals, polymers, gels, or LCM materials and improvement of inter-particle bond by sealants and gels can increase the load bearing capacity and strength of invaded formations. Gin-Fa Fhu[1] et al. demonstrated the effectiveness of sealing and strengthening using a blend of LCM materials and calcinated petroleum coke. Amanullah and Boyle[1] demonstrated the strengthening of sand pack of unconsolidated sand formation of gels and Espin et al. did the same by using a nano particle-based system

Impermeable barrier formation. The formation of impermeable mud cake eliminates mud pressure penetration effect and thus provides effective mud support by the differential overbalance pressure. Benaissa[4] et al. demonstrated the capacity of non-invasive fluid. Recent experiences with high performance water-based fluid demostrated the formation of an impermeable membrane to reduce pore pressure transmission and well bore strengthening

Near Wellbore Formation Dehydration. The chemical dehydration of formation due to difference of activities between the formation fluid and drilling mud causes strengthening of the shale formation near the wellbore. Oil-based and high membrane efficiency, high performance water-based mud produces strengthening by this mechanism.

In-situ Precipitation and Cementation. Fluid system triggering in-situ interactions, polymerization, precipitation, and cementation are used to improve formation strength. Mueller described the effect of sodium silicate to mitigate hole collapse in unconsolidated sand formations.

This paper states that wellbore strengthening provided by the calcium carbonate in flakes is a combination of Compressive Stress Cage and Sealing and Inter-particle bonding. Calcium carbonated flakes have been successfully used in the Cusiana field to drill the reservoir section containing fractured sands.[5]

Background

This novel technology was applied to drill wells in the highly unconsolidated sands of the deepwater Espirito Santo basin of Brazil. The basin is located southeast of the country with a water depth over 5,000 ft. (**Figure 1**). An additional objective was identified while drilling wells in a new block of the basin located between 1,500 and 2,500 ft. below the sea bed. The Arenito A was identified as a potential source of heavy oil (<15º API).

The Arenito A (**Figure 2**) is penetrated in the 12 ¼” hole section and the formation is constituted by high permeable loose sands. It is thought that heavy crude oil provides some bonding to the unconsolidated sands. The early wells drilled in the block presented severe hole enlargement in Arenito A sand and this leads to difficulties to proper evaluation of sands productivity. It was not possible to obtain core samples of the prospective formation due to the unconsolidated nature of the sands. The hole enlargement also prevented logging the well and DST produced negative results.

The **BR-01** well was drilled by using water-based mud[9] and severe hole enlargement was observed as indicated in **Figure 3.** The presence of hydrocarbons was determined by cuttings shale samples and three additional wells were planned. Changes in drilling fluid design were implemented to overcome the problems observed in the well.

Field Project Drivers

The difficulties encountered while drilling wells in the Spiritu Santos basin required optimization of drilling fluid design. The project drivers for the Brazilian project were:

- The need to reduce severe hole enlargement in Sand A;
- Logging the well as expected;
- Evaluate the potential of the heavy oil present in the unconsolidated sands.

Drilling Fluid Design

The first approach was the selection of oil-based mud to drill the section based upon good results by using the system in another areas of Santos basin[6].

The BR-02 and BR-03 wells were drilled by using oil-based fluid. Two wells were selected with the purpose of comparing drilling parameters by using the same fluid type. However, the hole enlargement by using oil-based drilling fluid was even higher when compared with water-based mud. (Refer to **Figure 3 and 8** for comparison.) This performance was unexpected due the ability of oil-based system to control hole enlargement.

A new approach was taken and the original water-based mud system was redesigned to solve the problem

Bridging and Well bore Strengthening

Lomba[8] et al demonstrated the benefits of using granular and flaked calcium carbonate for minimizing depth of invasion and internal and external filter cake thickness by using unconsolidated medium. The results indicate that particle size and shape seems to be the major factors governing fluid invasion. Based in those results it seems wise to select both type of calcium carbonate as part of a new drilling fluid design.

It is likely that the heavy oil constitutes partial bond of the loose sands of Arenito and the oil-based fluid solubilizes a portion of heavy oil and facilitated sand erosion. However, the hole enlargement observed by using water-based fluid indicated that fluid type is not the only cause of the problem. The successful application of flakes or laminated calcium carbonate to prevent lost circulation and fluid invasion in fractured sands has been applied very successfully in the Cusiana field of Colombia. This lead to the assumption that the use of flakes might contribute to the stabilization of the unconsolidated Sand A of Espitito Santo basin.

Laboratory Testing and Evaluation

Because flaked calcium carbonated is composed by deformable laminated particles it will bridge at the borehole interface of the high permeability sands. The regular calcium carbonate composed by round particles had less ability to bridge in the first step due its rigid structure. Bridging provided by flakes not only creates an internal filter cake but also contributes to the external filter quality. This bridging and sealing characteristic will help to protect the formation from excessive fluid invasion and the effective bridging appears to enhance the "rock strength" leading to more consolidated loose sands.

A testing program was designed to verify those assumptions and different grades of both regular and flaked calcium carbonate were selected to be used in the base water-based fluid. The results obtained by Santos[7] and Lomba[8] were used as guidelines for the laboratory testing program. Due to the lack of representative samples of Sand A, it was decided to select Macae Beach sand to simulate the invasion tests.

The filter media was composed of randomly sized particles of Macae sand and was packed in a API filter press. The criteria set for drilling fluid performance was the quality of internal filter cake and the total volume of filtrate. The following fluid compositions were evaluated:

Fluid 1 – Base Fluid - 15 ppb ground $CaCO_3$ 2-44μ;
Fluid 2 – Base Fluid - 6 ppb $CaCO_3$ Flakes Medium
Fluid 3 – Base Fluid - 6 ppb de $CaCO_3$ Flakes Fine;
Fluid 4 – Base Fluid - 15 ppb ground $CaCO_3$ 2-44 μ + 5 ppb $CaCO_3$ Flakes Medium + 2 ppb $CaCO_3$ Flakes Fine

Illustrations of the apparatus used for laboratory testing are indicated in **Figure 4** and **Figure 5**. The appearance of the sandpack after performing the test is shown in **Figure 7**.

Laboratory Results

The laboratory results are indicated in **Table 3** and **Figure 6.** The **fluid 4** formulation combining both type of flakes presented the best results and the total filtrate of 12 ml was produced after 1 minute.

The base fluid contained cationic amine used by the operator as standard fluid for the vertical wells in Campos, Santos and Espirito Santo basins. The final mud density of Fluid 4 formulation was 9.4 lb/gal

Case History 1: BR-01 well

The BR-01 well was the first well drilled in the new block by using water-based drilling fluid containing cationic amine for inhibition. This fluid type is commonly used in the Campos, Espirito Santo and Santos basin offshore Brazil. The section was drilled by using downhole motor and flow rates in the range of 1,000 gpm. Excessive hole enlargement and tortuosity was observed. (**Figure 3**). The presence of heavy hydrocarbons in cuttings shale samples was also detected. Additional three(3) wells were planned to evaluate the potential of new objective. A new strategy was discussed to be applied in the upcoming wells to overcome the observed hole enlargement which might compromise Sand A reservoir potential

Case History 2: BR-02 and BR-03 wells

The next two wells were drilled by using NA drilling fluid in an attempt to control hole enlargement by improving fluid inhibition. In addition, several drilling parameters that might have contributed to the observed problem were compared in BR-02 and BR-03 wells by using the same fluid. Those parameters included BHA type, ROP, flow rates, and bent housing (**Table 1**).

The caliper logs were not as expected and hole enlargement was even greater as compared with the application of water-based fluid in BR-01. (**Figure 8**).

These unexpected results lead to a change in the strategy and it was decided to return to the water-based formulation and explore changes in the fluid formulation

Case History 3: BR-04 well

Lessons learned from the previous experiences were the basis for improvement of the leaning process in the Espirito Santo basin. The organizational learning process is very important to improve the drilling practices in planning, operations, and review. The basics of the process features the following points:

- Defines specific goals linked with bottom line performance.
- Ensures that all actions are directed at meeting these goals.
- Remembers how decisions were made.
- Accurately monitors performance.
- Builds an accessible database.
- Uses this database to improve.

The laboratory results produced the basis for the novel drilling fluid design to be used in BR-04. In addition to this the following conditions were established to drill the BR-04 well:

- Pump rate was limited to 500 gpm for minimizing hole erosion and prevent bit balling problems
- The BHA constituted of tri-cone bit, 8” motor, rotative stabilizer, 0º rotating sleever
- The rotation was limited to 30 rpm

The BR-04 was drilled obtaining excellent caliper logs in front of the Sand A sand as indicated in the **Figure 9.** An illustration of proposed “strengthening mechanism” is indicated in **Figures 10,11,** showing SEM of the flakes**.**

Conclusions

Field case histories supported by laboratory work indicate that the novel approach of using laminated calcium carbonate (flakes) combined with ground calcium carbonate contributed to minimize hole enlargement in the unconsolidated sands A of the Espirito Santos basin. Good drilling and mud engineering practices contributed to the success. Several conclusive benefits were achieved with the addition of this sealing/bridging.

- The hole enlargement was reduced from 30-50% to 4% by using the novel approach
- The A reservoir potential was evaluated due improved well quality
- The stability of the loose sands were maintained after 336 hours of open hole exposure in BR-04 well indicating the effectiveness of ‘well bore strengthening “ mechanism
- The calcium carbonate flakes constituted the primary bridging/strengthening element due to shape and flexibility. Ground calcium carbonate seems to work on the top of the flakes to complement the effect.
- It is likely that flakes are able to “stick” to the heavy oil bonded between the sand grains to stabilize the structure.

Acknowledgments

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Nomenclature

Define symbols used in the text here unless they are explained in the body of the text. Use units where appropriate.

BHA = Bottomhole assembly

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Tables

Table numbers should appear above the tables with the title of the table.

Table 1 – Drilling Parameters

Well	BR-02	BR-03
Fluid Type	Oil-based	Oil-based
BHA	Bit full drift/9 5/8” motor	Bit full drift/9 5/8” motor
RPM	60	40
FLOW RATE	800	650
Ben-house	1º	0º

Table 2 – Drilling Fluid Formulations

Fluid Composition	Fluid 1	Fluid 2	Fluid 3	Fluid 4
CaCO3 ground 2-44	15			15
CaCO3 Flakes, Medium		5		5
CaCO3 Flakes, Fine			5	2

Figures

Figures captions should appear below the figure.

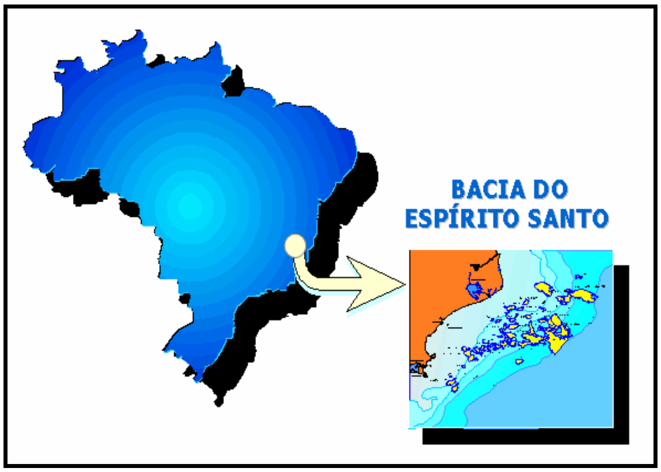

Figura 1 – Espiritu Santo Basin

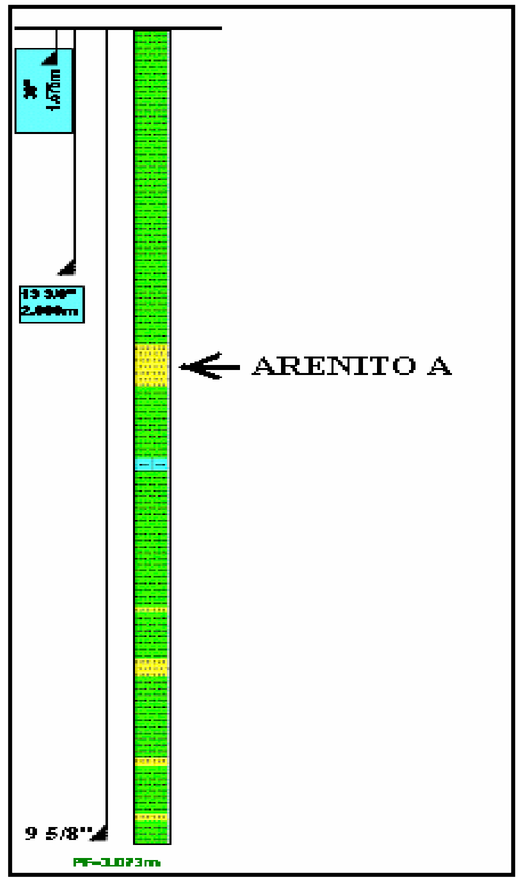

Figure 2 – Geological column BR-01 well

Figure 4 - Filter cell containing the Macae sand

Figure 5 - Filtration unit

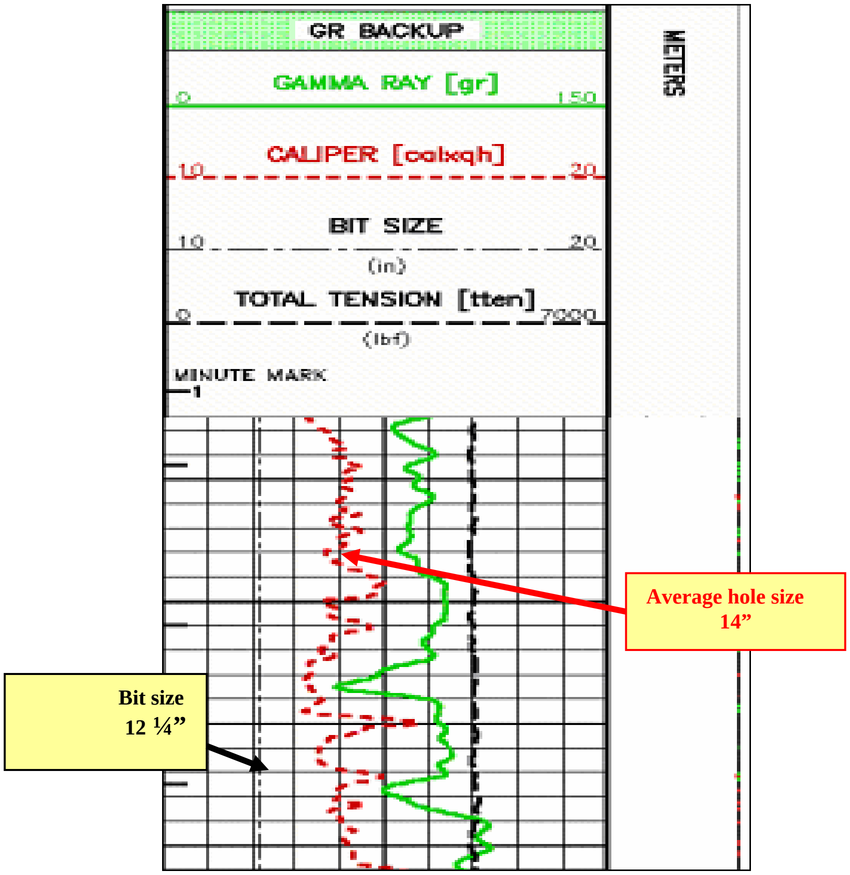

Figure 3 - Cáliper well BR-01

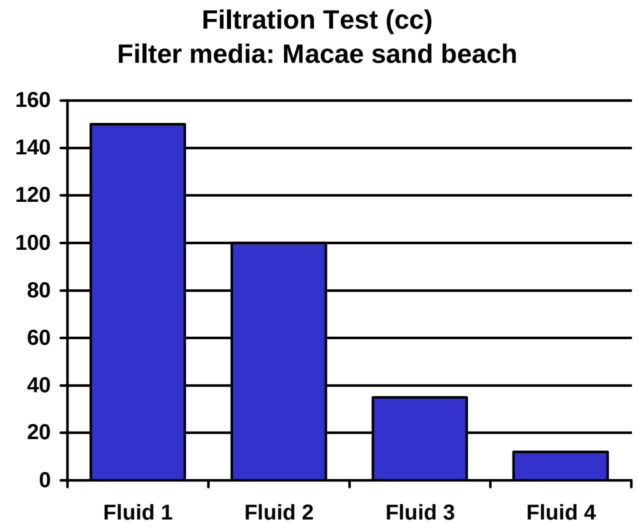

Figure 6 - Total filtrate by using simulated sand pack

Figure 7 - Sand pack after filtration test

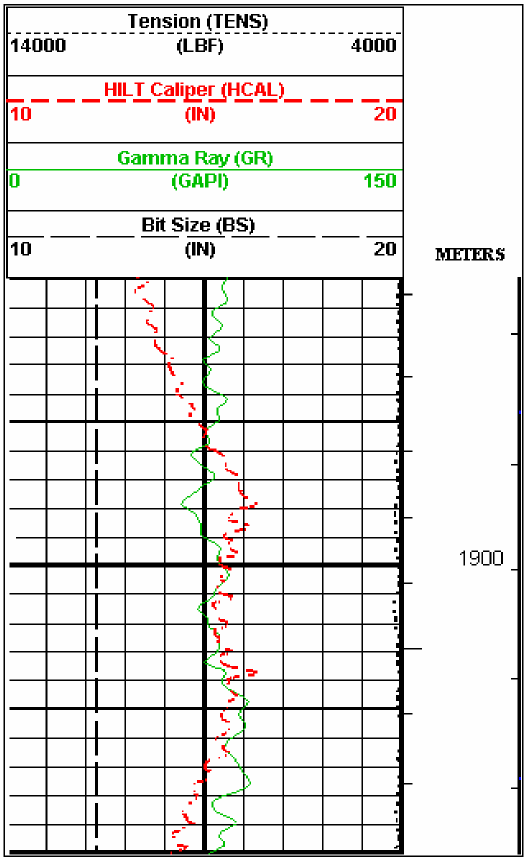

Figure 8 - Caliper well BR-03 by using oil-based

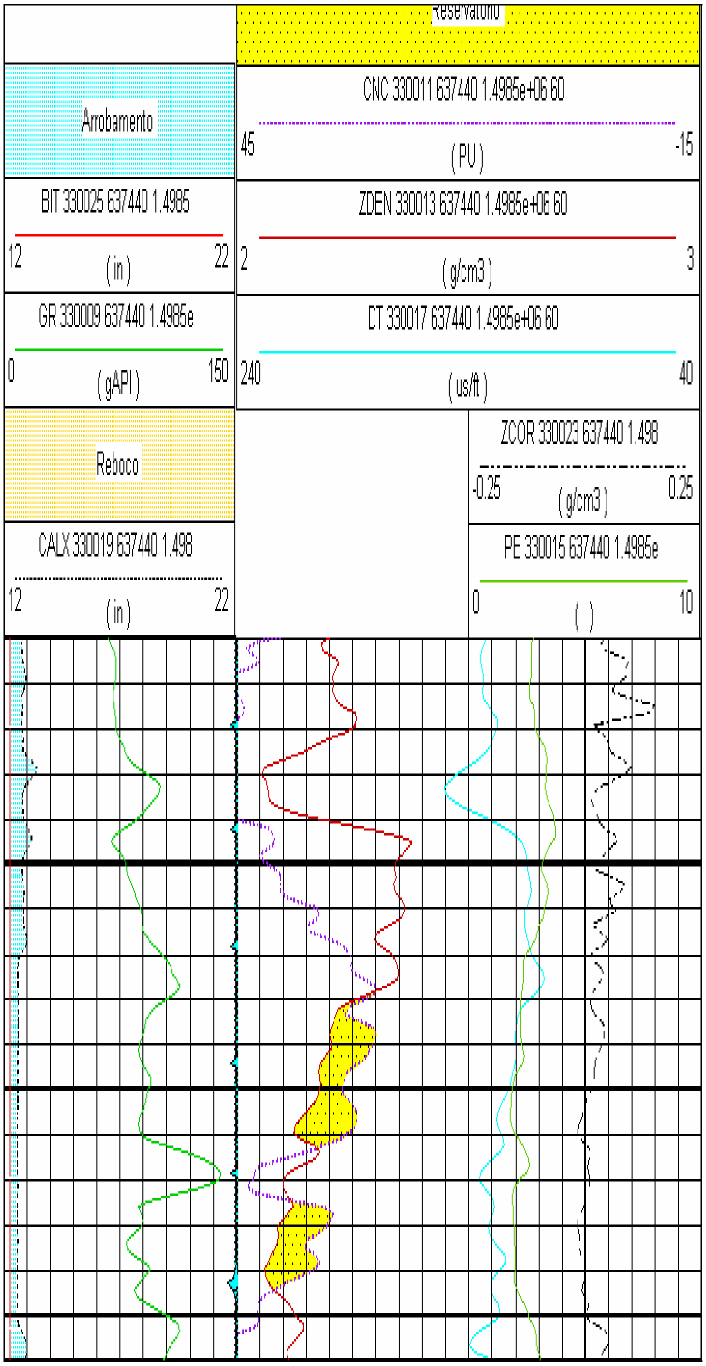

Figure 9 - Caliper well BR-04 where the novel drilling fluid was applied

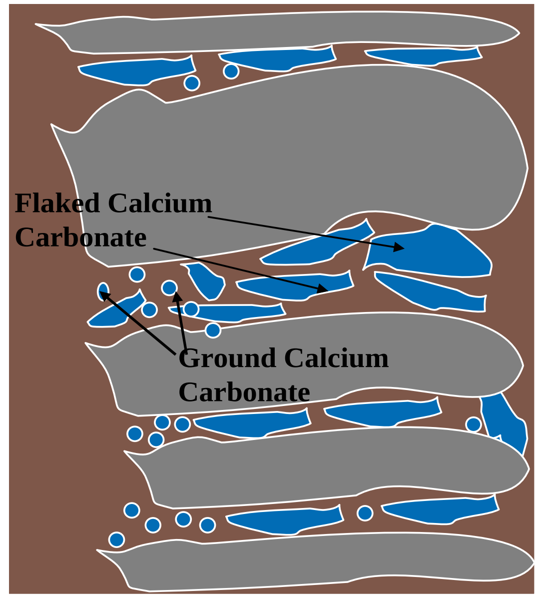

Figure 10 - Suggested "well bore strengthening" mechanism

Figure 11 - Calcium carbonate flakes