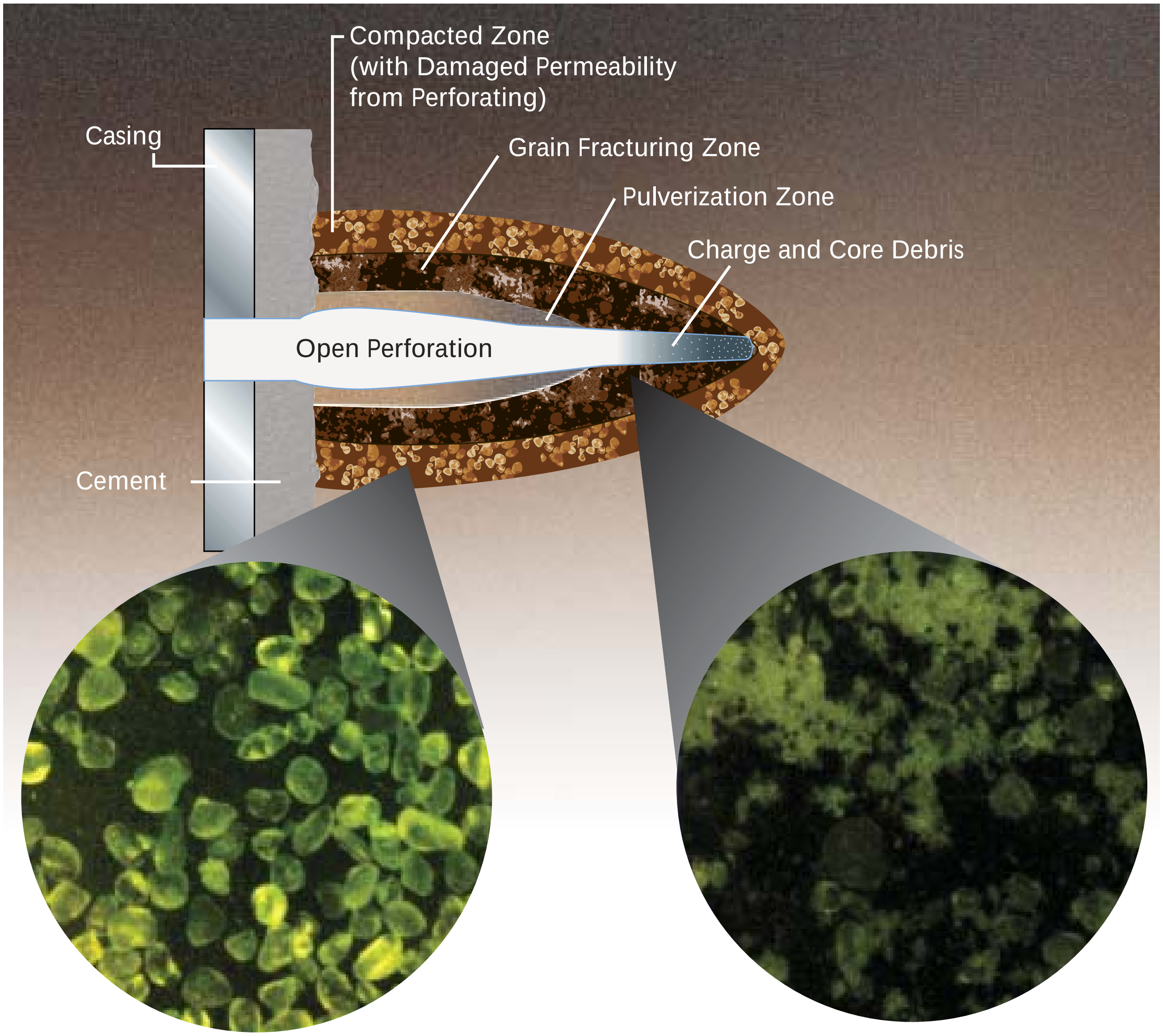


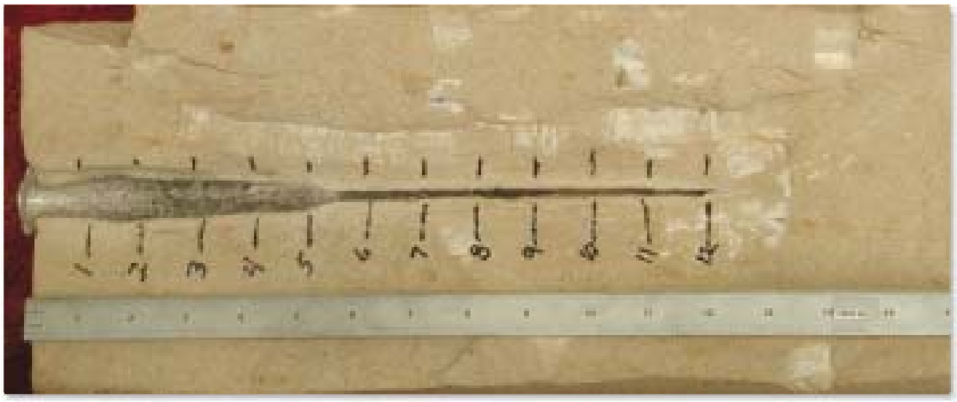
Microscopic photograph of undisturbed sand grains prior to perforating.

Microscopic photograph of damaged sand after perforating.

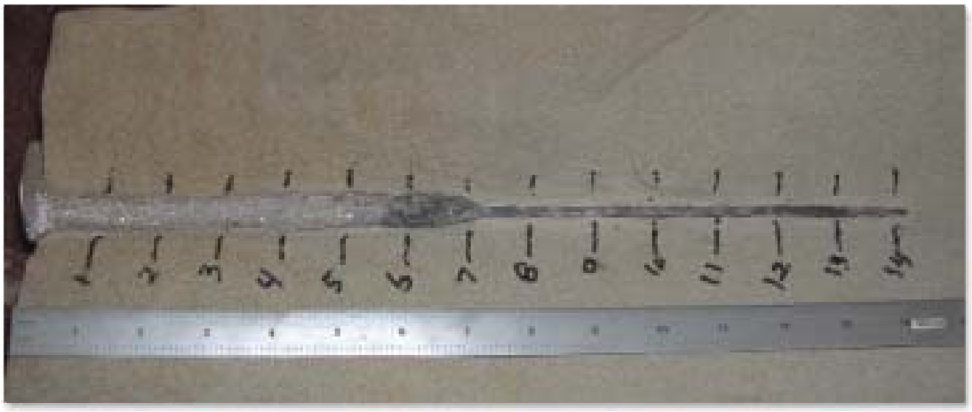
graphic illustrates how a deep penetrating (DP) shaped charge penetrates the wellbore components.

On a microscopic basis, the formation materials subjected to this very high load and load rate (millions of psi in microseconds at the jet center) shatter the individual formation sand grains, as well as reduce the cement particles to a very fine powder. This diminished particle size creates a surrounding filter cake, reducing permeability and inhibiting effective subsequent fluid injection. Because this new filter cake is so compacted, it is not easily removed by flushing or underbalanced perforating operations.

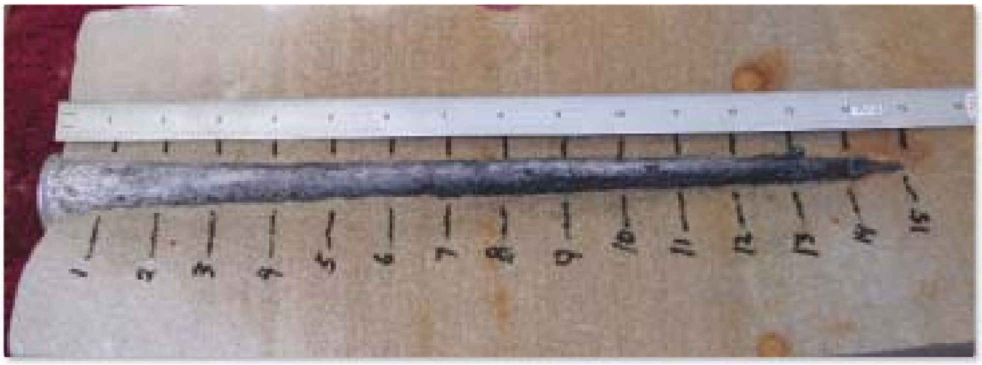
Shaped charge manufacturing companies, such as Halliburton's Jet Research Center are now spending significant amounts of funding and resources on combining perforating and flow testing in stressed permeable core samples. These tests clearly show that because a shaped charge penetrates a significant distance into the formation, it does not mean the entire perforation tunnel will allow fluid flow. Shaped charge design, overburden stress, rock type and permeability, and underbalance levels all have an impact the effective length of the perforation tunnel. It is common for a perforation that penetrates 15 in. (38 cm) into the formation to have only a flow contribution from the first half of the created tunnel. The following three figures show the same charge design, shot into the same formation permeability at underbalanced, overbalanced, and balanced conditions (Figures 1a, b, c). It



(a) *Figure a shows the effective length of the perforation, when a stressed Castlegate sandstone core was shot with 3500 psi (22 MPa) overbalance pressure and subsequently flow tested. The effective length of the perforation which would flow was only 5.5 in. (14 cm), although the perforation penetrated 12 in. (30 cm). In all three examples, the fluid in the sandstone's pore space was odorless mineral spirits and the permeability of the rock is approximately 1000 md. The decrease in total target penetration of this specific test is also due to a higher overburden stress.*



(b) *Figure b shows the effective length of the perforation, when a stressed Castlegate sandstone core was shot at balanced conditions and subsequently flow tested. The effective length of the perforation which would flow was only 7 in. (18 cm), although the perforation penetrated 14 in. (35 cm).*



(c) *Figure c shows the effective length of the perforation, when a stressed Castlegate sandstone core was shot with 3500 psi (22 MPa) underbalance pressure and subsequently flow tested. The effective perforation would flow almost its entire length of 15 in. (38 cm). It is important to note that 3500 psi (22 MPa) underbalance, generally considered an extremely high level, in this high permeability sandstone with liquid filled pore space, and cannot always be achieved for operational reasons.*

Figure 1 – *Stressed Castlegate sandstone cores perforated at various pressure differential conditions.*

can clearly be seen that underbalanced conditions can improve the perforation's effective length, but there still is a significant length of the perforation tunnel that does not contribute to flow.

To solve this problem, the StimGun™ assembly, and its family of products, use a high energy gas pulse, with a significantly lower pressure loading rate – thousands of psi in milliseconds – to break through this hard filter cake and create a pathway into the formation, enabling further fluid injection or enhancing the well's inflow performance. The force of the pulse also removes materials plugging the perforations and redistributes them farther into the fractures or back into the wellbore. Many of those individuals intimately familiar with perforating believe the industry as a whole will be moving towards more flow testing work and tailored perforating charges specifically designed for the operator's formation characteristics, as well as the use of propellant technology to enhance inflow performance. Operators may very well move away from API charge penetration data and more towards a focus on perforating for flow. The next article, does an excellent job of showing some of the productivity enhancements which can result in not only improved perforating performance, but also using the propellant to break down the perforations with very short fractures of varying conductivity.