Geostatic (Overburden) gradient.

Formation strength may be assumed and considered as related to the geostatic gradient (Overburden) commonly taken as being equal to **1.0 psi/ft.**

Thus when a formation is not subjected to abnormal internal stress *i.e. is considered to be in a relaxed techtonic sediments, formation strength is sometimes quoted as equal to 85% of the geostatic gradient (overburden) i.e. 0.85 psi / ft.* However this should not be taken as a reliable boundary since other conditions must be considered.

Geostatic (Overburden) pressures are measured from the rig floor, hence offshore the depth and density of sea water must be taken into account.

The geostatic (Overburden) density is taken as the average density to the depth of interest.

Because of compaction, the overburden gradient is not constant

However as the bulk density of the rock approaches the density of the matrix due to very low porosity, compaction with further depth will be exceedingly slow hence porosity effect will become negligible.

Since it is known that the density of a thick sedimentary sequence is approximately 2.3 sg, with depth the overburden gradient will be about 1.0 psi /ft.

2.3 sg x 0.4335 = **1 psi / ft.**

Onshore : Sediments are more compacted the overburden gradient may be assessed to be close to 1 psi / ft.

Offshore : Overburden gradients are less due the effect of seawater, air gap and the larger thicknesses of UNCONSOLIDATED sediments.

Dependant upon WATER DEPTH , offshore overburden gradients may be as low as 0.73 psi/ft @ 5000 ft below the mud line.

Finally it is important to remember that accurate bulk densities must be obtained in order that the overburden gradient is as accurate as possible and that all litholigies present in the formations must be considered.

Typical densities of rocks and fluids.

Lithology	Matrix density (SG)
Sandstone	2.65
Limestone	2.71
Dolomite	2.87
Anhydrite	2.98
Halite	2.03
Gypsum	2.35
Clay	2.7 - 2.8
Freshwater	1.0
Salt water	1.15
Oil	0.8

Geostatic gradient (Overburden) - porosity

The geostatic gradient (Overburden) will vary considerably with the porosity present in the formations that are drilled.

The sedimentary density is the total bulk density of the rock , consisting of a mineral and a fluid contained within its pores . The Geostatic gradient (Overburden) as illustrated below can be calculated if such values were known or available.

Offshore surface clay (porosity 70%)
Mineral density 2.65 SG

Geostatic gradient = (0.3 x 2.65 x 0.433) + (0.7 x 0.465)
= **0.67 psi /ft.**

Freshwater sand, (porosity 40 %)

Geostatic gradient = (0.6 x 2.65 x 0.433) + (0.4 x 0.433)
= **0.86 psi / ft**

Note :

The **porosity of shales decreases rapidly** with depth
: ± 2000 ft , from 70% to ± 32% and then gradually to ± 10% @ 20,00ft.

While the **porosity of sand decreases gradually** and fairly steadily with depth from 40% to 20 %

Therefore :

A formation that is mainly shale down to 2000 ft has a lower geostatic gradient than if it were predominantly sand.

Below 2000 ft shales will tend to have a higher geostatic gradient , because their porosity is generally less than that of the sands.

Effect of faulting on formation strength.

In a normally faulted area, the minimum formation strength is believed to be ± 64% of the overburden - geostatic gradient. i.e. **± 0.64 psi / ft**

In an area of reverse or thrust faults , formations may approach the overburden value, e.g. **0.85 to 1.0 psi / ft.**

Techniques used to predict , detect and evaluate formation pore pressures.

Data source	Data / Indicators	Stage of well
Offset wells	Mud loggers reports Mud weights used Kick data Wireline log data Formation test data Drillstem test data	Planning Drilling comparisons
Geophysics	Seismic	Planning
Drilling parameters	Drilling trends Drilling rate Drilling exponents Other drilling rate methods Torque & Drag MWD logs	Drilling
Drilling mud parameters	Gas levels Flowline mud weight Flowline temperature Resistivity, salinity and other mud properties Well kicks Pit levels Hole fill up Mud flowrate	Drilling
Cuttings parameters	Bulk density Shale factor Volume, shape and size Other methods	Drilling
Wireline logs	Sonic Resistivity Density Combining logs	After drilling
Direct pressure measurements	Wireline tests Drillstem tests	ProductionLogging Well testing Completing

The above are discussed in greater detail in section 6 " Primary well control " of this manual.

Importance of tests to establish formation strength values.

Each formation drilled will have a certain strength and may vary greatly depending upon the geological and other characteristics present.

For each formation drilled through, its formation strength may not always exactly be known. Also, the strength is reduced as soon as breakdown of its formation occurs. If this occurs, **The original or initial formation strength cannot be regained .**

After breakdown, formations are weaker than before

It is important that this is borne in mind when formation pressure tests are being carried out or are required during drilling and well servicing operations.

From the above finally it can be seen that it is difficult to assume formation strength values and should be readily appreciated that it is essential to carry out strength / integrity tests in the well being drilled unless reliable values are available.

Formation pressure tests.

Formation pressure tests are carried out with high pressure, small volume pumps and require precise, well-defined pressure gauges, volume measurement devices etc. As soon as the pressure gauges indicate that the formation starts taking fluid then the pump would be stopped to prevent formation breakdown occurring and the system pressure would be bled back to the test returns tank with returned volume accurately measured.

Pumping a small volume of mud into a formation generally will only deter the immediate surrounding area of the hole and not further effect the strength of the formation although this is at times dependant on the type of formation that is being tested. Hence the requirement for such pumping systems as described above.

Dependant on the depth and the formation type being tested, test pressures required may vary from a few hundred to three or four thousand *(psi.)* hence a range of suitably defined gauges is necessary to accurately assess leak off pressures.

A gauge manifold offering a wide range of pressures is preferred when carrying out formation pressure tests. This allows the most suitable pressure range to be selected for the formations and test pressures required as testing progresses. Computerised pressure monitoring is now commonly provided by the cementing contractors for such purposes.

Upper pressure limit.

The **initial formation strength** establishes the **upper limit** of our pressure balance . When the *pressure at any specific point in the wellbore goes above the upper limit* , *balance can be restored* , but ***the upper limit is now lower than before.***

Operating within the limits established.

It can be concluded that **all drilling operations** in the open hole *(i.e. drilling, reaming, tripping, running logs, setting casing, cementing,)* **must be carried out whilst staying between the two limits.** *(i.e. the upper and lower limits within the wellbore.)*

The lower limit is generally known or can be tested without changing .

The upper limit may not be known and, when broken through, will be substantially reduced in the majority of instances.

It is therefore logical to stay closer to the lower limit, in other words to drill with the lowest possible mud density.

How close to the lower limit that could be achieved depends on local conditions, variation in pressures expected, when drillstring or casing strings are run into or pulled from the wellbore etc.

To avoid reducing wellbore pressure below the lower limit when maintaining drilling operations, a drilling fluid must have a mud density that allows a certain degree of overbalance to prevail.

Wall cake.

A thin layer of mud and solids plastered against the formation wall *(especially permeable formations)* will form a thin, tough, impermeable membrane that will allow maintenance of an overbalanced situation by providing a seal to support the differential pressure exhibited between the hydrostatic head of the mud and the formation pressures presented.

Wall cake will therefore prevent substantial mud loss to the formation and will support a large degree of overbalance, depending on it's characteristics and those of the formation, *(mainly permeability)*

When the pressure differential becomes to high, wall cake and the formation will however breakdown, with resultant mud losses or flow from the formation into the well occurring.

The lowest combined wall cake - formation strength in the open hole will establish the upper limit for the hydrostatic pressure that can be applied down hole. If this value is exceeded a balanced condition may subsequently be re-established, but the formation will have probably been damaged, and the upper limit will be effectively decreased.

With TIME however the original formation strength may be regained or even improved by the reinforcement provided by the fine solid particles from the mud.

Effective overburden pressure.

The effective overburden pressure is that portion of the overburden pressure that is not supported by the pore pressure. The effective overburden pressure is therefore calculated by

$$E = O - P$$

E = Effective overburden pressure
O = Overburden pressure
P = Pore pressure

The effective overburden pressure has no application in pressure evaluation apart from when considering fracture pressure calculations, nevertheless it is important in understanding the relationship between pore pressures and overburden pressures.

As the pore pressures increases, more of the overburden becomes supported - reducing the effect of overburden pressure. When the pore pressure is equal to the overburden pressure , the effective pressure is 0, and when this occurs , gravity sliding , diapirism and other induced deformation may occur.

Since the effective overburden pressure is that which causes compaction, compaction may still occur in geo pressured zones generally at a slower rate , unless pore pressure is equal to the overburden pressure.