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ORIGIN AND GENERATION MECHANISMS OF GEOPRESSURES IN SHALE DOMINATED SETTINGS WORLD-WIDE: A REVIEW.

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ABSTRACT

Geopressures are common in young Tertiary sedimentary basins where marine units underlie rocks of higher permeability. A low permeability environment and conditions that reduce available pore space or increase fluid volume are necessary for geopressures to occur and be maintained. In the Niger Delta, Gulf of Mexico, and indeed worldwide, the generation of geopressure is often related to the sedimentation rate, while its dissipation depends on the hydrological properties of the sediments(that is porosity, permeability, etc).Geopressures influences many fluid related aspects of petroleum geology including diagenesis, migration and accumulation of oil and gas ,and indeed reservoir quality. It also constitutes a hazard in drilling wells and directly impacts on drilling costs and the safety of petroleum exploration. The general overview of the different casual mechanisms and their relative contributions to the present day geopressure regime is indeed very important. The objective of this work is therefore to review the different mechanisms of geopressure and to assess the relative contributions of individual mechanisms to geopressure development. A primary objective here is to critically evaluate the relative importance of each.

KEY WORDS: Generation Mechanisms, Shale, Geopressures, Undercompaction, Fluid Expansion.

INTRODUCTION

Shales normally constitute more than 80% of sediments and sedimentary rocks in siliciclastic environments like the Niger Delta Basin and Gulf of Mexico. Geopressures influences many fluid related aspects of petroleum geology including diagenesis and reservoir quality. Similarly, the processes of migration and accumulation of oil and gas are strongly influenced by overpressured systems (England et al, 1987; Hunt, 1990). It also constitutes a hazard in drilling wells and directly impacts on drilling costs and the safety of petroleum exploration.

The general overview of the different casual mechanisms and their relative contributions to the present day overpressure regime is supported by different key publications (Fertl, 1976; Magara, 1978; Osborne and Swarbrick, 1997; Miller and Luk, 1993; Luo and Vasseur, 1993; Bowers, 1995; Grauls, 1997). The mechanisms proposed for increasing fluid pressure in sedimentary basins include:(a) Rapid loading causing compaction disequilibrium that is common in fine grained rocks (Chapman,1982; Magara,1978; Swarbrick, 1995; Hunt, 1979);(b) Fluid expansion mechanisms resulting in unloading of the compaction curve (Bowers, 1995; 2002; Ward, 1995; Bowers and Katsube, 2002; Sayers, 2006; Chopra and Huffman, 2006);(c) Effect of gas buoyancy in sealed units (Swarbrick, 1995; Grauls, 1999);(d) Hydrocarbon generation (Timko and Fertl, 1971; Law and Dickinson, 1985; Spencer, 1987) and oil-to-gas cracking (Chaney, 1950; Barker, 1990, Luo and Vasseur, 1996);(e) Smectite to illite transformation and clay dehydration (Powers, 1967; Burst, 1969; Schmidt, 1973);(f) Aquathermal expansion and thermal expansion of fluids (Barker, 1972; Bradley, 1975; Plumley, 1980; Miller and Luk, 1993; Hunt, 1990; Alnes and Lilburn, 1998); (g) Compression / lateral tectonic stress (Berry, 1973; Grauls, 1999) and (h) Osmosis in shales (Marine and Fritz, 1981; Grauls, 1999). Generating overpressures from the latter three mechanisms are considered to be small in most cases (Swarbrick, 1995). The contribution of horizontal compression to overpressure generation is considered to be minor in passive continental margin basins (Swarbrick and Osbome, 1998).

The objective of this work is therefore to review the different mechanisms of geopressure and to assess the relative contributions of individual mechanisms to geopressure development in siliclastic environments. A primary objective here is to critically evaluate the relative importance of each.

Subsurface Pore Pressure Terminology

Figure 1 is a schematic diagram of pressure versus depth profile illustrating several concepts and of course geopressure terminologies. The overburden stress or lithostatic pressure is the pressure exerted by all overlying materials, both solid and fluid. Below the water bottom, this line has an approximate slope of 1psi/ft, but the true slope depends on the density of the rock and tends to increase with depth because rock density tends to increase with depth. Effective stress is the difference between overburden stress and pore pressure; essentially the amount of overburden stress that is supported by the rock grains. The effective stress is related to the overburden orlithostatic pressure and pore pressureby the relation in equation 1.It is the arithmetic difference between lithoststic pressure and pore pressure.

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$$\sigma_{eff} = OVB - \alpha * P_P \ldots\ldots\ldots\ldots\ldots (1)$$

Where σ_{eff} = effective stress, OVB =overburden stress,P_P= pore pressure and α = poro- elastic coefficient which is lithology dependent.

The pore pressure is the pressure of the fluid in the pore space of the rock. This can be higher than hydrostatic pressure. Pore pressure

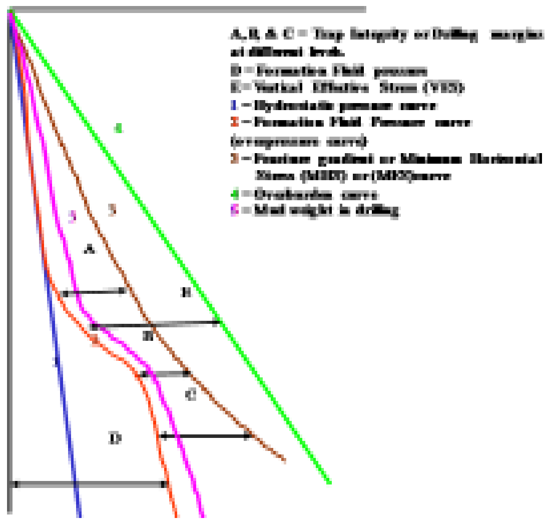

Fig. 1. Geopressure and stress terminology

does not reach overburden stress. As pore pressure approaches overburden stress (actually, the least principal confining stress which is usually less than overburden stress), fractures in the rock open and release fluids and pressures.

Hydrostatic pressure is an important concept. This normal or hydrostatic pressure is simply the pressure due to a column of water. The hydrostatic line gives the pressure due to a column of water. The slope would be 0.433psi/ft for pure water, but is usually 0.45 – 0.465psi/ft for formation waters (saline).Overpressure also called excess pressure or geopressures may be defined as the difference in fluid pressure at some point in the subsurface, between the actual fluid pressure and the predicted hydrostatic fluid pressure. Geopressures are actually present everywhere in the subsurface where fluids are moving, as this pressure is the basic driving force for fluid movement.

Theory

In the Niger Delta and indeed worldwide, the generation of overpressure is often related to the sedimentation rate. Although numerous mechanisms have been proposed for the origin of overpressures, it is possible to derive a general expression for their generation rate based on the concepts of rock and fluid mass conservations which describes the most reasonable generation mechanisms. For a porous medium the conservation of mass of the fluid and solid phases with respect to fixed space coordinates may be expressed by a basic hydrodynamic equation given as follows (Luo and Vasseur, 1992; Audet and Mc Connell, 1992):

$$\frac{\left(\frac{\varphi\beta + \propto_\varphi}{1-\varphi}\right)\frac{dP}{dt} = \frac{1}{\rho}\nabla.\left\{\frac{\rho_k}{\mu}\left(grad\vec{\rho} - \rho\vec{g}\right)\right\} + \propto_\varphi}{1-\varphi} . \frac{ds}{dt} + \propto_\varphi \frac{dT}{dt} + q \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where

$\frac{dP}{dt}$ = rate of change of excess fluid pressure i.e. pressure above hydrostatics.

$\left(\frac{\propto_\varphi}{1-\varphi}\frac{dP}{dt}\right)$ and $\left(\frac{\propto_\varphi}{1-\varphi}.\frac{ds}{dt}\right)$ = Represent the effect of compaction.

$\left(\alpha_{\varphi} \frac{dT}{dt}\right)$ = pressure generation/ dissipation term as a result of temperature (T) changes i.e. aquathermal effect.

q =represents the discharge of fluid volume within the pores by reactions and processes like clay mineral dewatering, which in turn will generate excess pressure.

$\frac{1}{\rho}\nabla.\left\{\frac{\rho_k}{\mu}\left(grad\vec{p} - \rho\vec{g}\right)\right\}$ = an excess pressure dissipation term, i.e. how fast lateral or vertical flow can drain the excess pressure (this term is essentially a form of Darcy's law).

Equation (1) above demonstrates that fluid movement is intimately linked to excess pressures which are generated primarily by increasing vertical load. This governing equation for excess pressure generation relates the vertical effective stress history to the rate of dissipation of excess fluid pressure (geopressures) and the spatial gradient in the excess pressure of fluid velocity field. The dissipation of overpressure depends on the hydrological properties of the sediments (that is porosity, permeability, etc).

Loading And Unloading Of Sediments

Geopressure most commonly occurs when low permeability sediments inhibit pore fluid from escaping as rapidly as the pore space would like to compact. Excess pressure develops as the weight of newly deposited sediments squeezes the trapped fluid. Because the fluid has a low compressibility, it supports a majority of the additional overburden load, and retards further compaction. As a result, the effective stress and sonic velocity change more slowly during subsequent burial than they would under normal pressure conditions. This effect is shown on a plot of velocity versus vertical effective stress as a loading curve (see figures 2a).

A marked decrease in sonic velocity, or increase in sonic transit time has conventionally been attributed to overpressure .Surdam et al (1997) among others suggest that fluid type, effective rock stress, lithology, matrix compaction, salinity and bed thickness can also affect sonic velocity. Though velocity reversal zones are indicative of formations that have undergone unloading, not all velocity reversals are the result of unloading. The velocity will also drop across a transition from a normally pressured sand/shale sequence to massive, undercompacted shale. It is believed that a reversal in consolidation occurs when sediments are unloaded, either in response to a decrease in total stress or by fluid expansion geopressure generating mechanisms(Ward, 1995).Sediments are not elastic and do not recover back along the loading path but regain only part of their original volume along an unloading path(figure 2b). There is strong evidence that sediments recover some part of their volume when total stress is reduced. During unloading by stress relief, rocks rebound and recover only part of their original volume by elasto-plastic and crack propagation mechanisms. Neuzil and Pollock (1982) proposed that pore pressure is significantly reduced during erosional unloading of sediments that are sufficiently low in

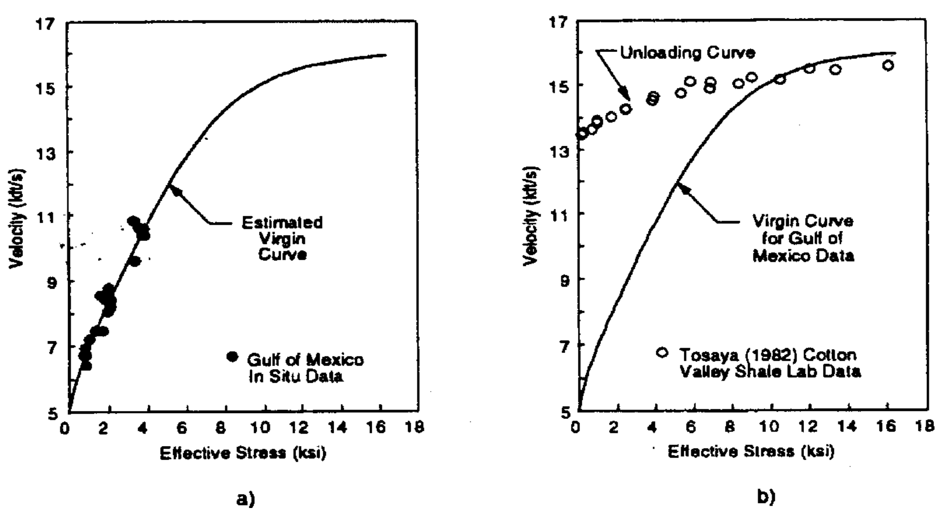

Fig.2: Shale compaction behavior showing (a) virgin curve (b) unloading curve (from Bowers, 1995).

permeability such as shales. It is believed that tectonic stress should also lead to unloading and reduction of pore pressures in a similar manner. Similarly, it has been proposed that fluid expansion or charging mechanisms also unload the sediments and that this process can be observed through strain parameters such as velocity (Bowers,1995) and porosity (Ward et al 1995).

Origin And Generation Of Geopressures

In order of importance, the different causal mechanisms of geopressures are: mechanical stresses, thermal effect, dynamic transfers, chemical stresses and others. These are the main factors responsible for generation of abnormal pressures in present day hydrocarbon systems.

1) Mechanical Stresses

In recent sand-shale dominated Tertiary basins, the weight of overburden or vertical stress contributes to the development of overpressure in poorly drained, low permeability shale prone intervals. Mechanical stresses include the following mechanisms: compaction disequilibrium and lateral stresses (strike–slip fault and thrust faults).Since Dickson (1953), the compaction disequilibrium phenomenon has been considered by many authors as the main cause of geopressures in sedimentary basins (Fertl, 1976, Magara, 1978).The magnitude of this pressure regime was quantitatively assessed from soil mechanics developed by Terzaghi (1948).

i) Compaction Disequilibrium

Compaction is a term used when porosity decreases and density increases during burial and includes mechanical and chemical processes: Mechanical compaction is the process of volume reduction via pore water expulsion within sediments due to the increasing weight of overburden load. The requirement of its occurrence is not only the application of an overburden load but also the expulsion of pore water. Mechanical compaction will expel pore fluids, re-arrange grains, and make a more effective grain packing that will distribute the vertical effective stress onto an increasing number of grain contacts. Mechanical compaction starts immediately after deposition and is driven by the effective vertical stress from the increasing overburden. The extent of compaction is strongly influenced by burial history and the lithology of sediments. The freshly deposited loosely packed sediments tend to evolve, like an open system, towards a closely packed grain framework during the initial stages of burial compaction and this is accomplished by the processes of grain slippage, rotation, bending and fracturing. Such re-orientation processes are collectively referred to as mechanical compaction, which generally takes place in the first 1-2km of burial. After this initial porosity loss, further porosity reduction is accomplished by the process of chemical compaction such as pressure solution at grain contact.

Chemical compaction involves dissolution and precipitation of minerals and is mainly controlled by temperature over time (Storvoll and Brevik, 2008). When cement (e.g., quartz in sandstone) starts to precipitate, the grain contacts will become even more stable as they are prevented from further adjustments, and the stress will be distributed on even larger surface areas because of the cement itself. The increase in vertical effective stress by continued burial will then become insufficient to overcome the strength and stability of the grain framework. This results in the end of mechanical compaction and the beginning of chemical compaction. Pore pressure will have minor or no influence on the porosity reduction in the chemical compaction domain. Chemical reactions, such as those that occur during chemical compaction in sedimentary rocks are controlled by the reaction kinetics. Reaction kinetics refers to the rate of change in chemical reaction (e.g., mineral transformation during chemical compaction).The physical state of the reactants (solid, liquid, or gas), the concentration, temperature and the presence of catalysts can influence this rate. Temperature, however, is the most important factor, also in siliclastic rocks. In a sandstone, the onset of quartz cementation and transition from mechanical to chemical compaction starts at 70-80^{0}C (Storvoll and Brevik, 2008).

Sediment consolidation follows the porosity effective stress-loading path. This is the normal sediment burial compaction path if full fluid escape is permitted in response to the increased vertical stress. In this case as the sediment pile thickens, porosity decreases, effective stress increases and the pore pressures remain hydrostatic. If however, fluid escape is fully restricted which may occur in a thick low permeability shale section for example, then the porosity and effective stress do not change. With continuing sedimentation, since effective stress remains constant, pore pressure increases at the same rate as the overburden, developing overpressures. This mechanism is called disequilibrium compaction or undercompaction. Similarly, where sediments have experienced a high burial rate and subsequently rapidly increasing temperatures, this often results to chemical compaction disequilibrium. This means that some of the chemical mineral reactions in the shales have not had enough time to be completed relative to the present day temperatures (Storvoll and Brevik, 2008).

(ii) Lateral Stresses (Tectonic Stresses)

Tectonic stress may increase the total stress state leading to the generation of extreme overpressures. This has been documented in areas known to be under high lateral stresses such as parts of California (Berry, 1973). In a basin where no lateral compression occurs, horizontal stresses would be equal to or less than vertical stresses. Lateral compression can increase pore pressures in the same way as vertical stress can cause over pressuring through disequilibrium compaction.

Geopressure buildup due to the tectonic processes can be very rapid and decrease of pressure can be similarly rapid if large volumes of fluid driven by seismic valving or pumping escape up fault planes. Fault zones such as San Andreas are particularly susceptible to failure because ductile creep in the fault zone leads to compaction that increase fluid pressure and makes the fault weak. The contribution of present day lateral stresses or compressive tectonics, as a possible geopressure mechanism is rarely considered and remains strongly underestimated, despite the considerations made by Finch (1969), Berry (1973) and Grauls and Baleix (1993) in strike – slip fault contexts. In summary, tectonic causes of overpressuring are feasible, but poorly understood due to the geological complexities of the basins in which lateral compression occurs. However, the effects of tectonic processes are most important in basins that are tectonically active today.

(2) Thermal Stresses

The volumetric expansion of water or "aquathermal effect" was proposed as a main overpressuring mechanism by Barker (1972). Thermal stresses include such processes as aquathermal expansion, fluid expansion, kerogen cracking to oil generation and oil cracking to gas generation (hydrocarbon generation).

i) Aquathermal Pressuring

Aquathermal pressuring occurs in a rock system that is close to perfectly sealed and sustains a constant volume as temperature rises i.e., pore volume expansion must be less than the thermal expansion of water at constant pressure (Osborne and Swarbrick, 1997). Aquathermal pressuring is thought by some authors to be important only where there is no compaction as subsidence progresses and where Darcy flow does not occur (Luo and Vasseur, 1992). It is therefore believed to be unlikely to occur unless rocks can have effective permeabilities that are lower than those measured in real shales. An additional objection to aquathermal expansion as a main cause of overpressuring is that in many overpressured rocks there is a transition zone of increasing pressure into the highest overpressured section. A gradual transition zone implies permeability; hence the section is not fully sealed and cannot fulfill the requirements for aquathermal pressuring (Chapman, 1980).

However, several authors (Daines, 1982; Alnes and Lilburn 1998, Bowers, 1995; Miller and Luk, 1993) strongly believe that aquathermal pressuring is a major source of overpressures. It is believed that thermal effects are potentially important in most basins where geothermal gradients near 30^0c/km are common. For undrained conditions, it is evident that thermal expansion can cause unloading even in relatively "cool" basins, as long as Darcy fluid flow is severely restricted.

ii) Fluid Expansion Mechanisms

This mechanism formally proposed by Bowers (1995) is believed to be the dominant cause of overpressure at depth in most sedimentary basins. Aquathermal expansion and clay diagenesis acting together explain many of the rapidly increasing pressure gradients observed worldwide. Overpressure can be caused within the pore space by (charging) fluid expansion mechanism such as heating, hydrocarbon maturation, and the expulsion/expansion of intergranular water during clay diagenesis. Here, overpressure results from the rock matrix constraining the pore fluid as the fluid tries to increase in volume. Load transfer from smectite grains to pore water during illitization is another potential way clay diagenesis can cause overpressure. These mechanisms are thought to generate the extreme overpressures, which approach or even exceed the fracture gradient in many basins worldwide.

The first occurrence of these extreme geopressures has been observed to be temperature dependent. Many of the fluid expansion mechanisms increase with temperature, and therefore depth. To be a strong source of overpressure, fluid expansion also requires a fairly rigid, well–compacted rock matrix that can adequately constrain the pore fluid. Consequently, fluid expansion is more likely to be an important source of geopressure at deeper depths in stiffer rocks (Schmidt, 1973; Leach, 1993; Ward, 1995; Bowers, 1995).

iii) Kerogen Cracking To Oil Generation

The change from solid kerogen to liquid hydrocarbon, gas, residue and by-products is accompanied by a volume expansion (Meissner, 1978). In a closed system, this could lead to the generation of geopressures. Evidence for pore pressure increase during organic matter maturation is provided by primary migration of hydrocarbons from low permeability source rocks. Primary migration implies high internal pore pressures within the source rocks, resulting in the release of oil through micro- pores or micro - fractures (England et al; 1987). Buoyancy pressure alone is not sufficient to allow primary migration. In addition, the top of the geopressured section is commonly coincident with the zones of hydrocarbon generation (Spencer, 1987; Evamy 1978).

For kerogen maturation to result to geopressure on a basin wide scale, it is obvious that a thick, areally extensive, mature source rock with high total organic carbon must be present; otherwise only local overpressure within the source will be generated (Burrus et al., 1993).

Iv) Oil Cracking To Gas Generation

Methane gas is generated biogenically within sediments during shallow burial at temperatures of greater than 80^0C (Barker, 1987). In addition, gas hydrates can form in relatively shallowly buried reservoirs at low temperatures and high pressures. As subsidence progresses and temperature rises, hydrates become unstable and gas is released as free gas, potentially causing geopressuring due to volume increase (Hunt, 1979). This gas release is likely to occur at temperatures between 21 and 27^0C. At much higher temperatures, oil converts to lighter hydrocarbons and ultimately to methane by thermal cracking. Temperatures of 120 – 140^0C are required, with almost complete cracking to gaseous hydrocarbons (mainly methane) at temperatures in excess of 180^0C (Hunt, 1979; Tissot and Welte, 1984). Gas generation is thought to be accompanied by a volume expansion that can lead to the production of extreme geopressures in a closed system.

The major problem with the gas generation/oil cracking mechanism is that pressure most likely retards the reaction. Thus, development of significant geopressure would be inconsistent with gas generation (Osborne and Swarbrick, 1997). Quantification of these processes is clearly needed for their integration into basin models.

3) Dynamic Transfer

Overpressures, generated most often below 3000m, play a key role in secondary hydrocarbon migration and more generally in fluid dynamic transfers. Dynamic transfer includes hydrofracturing, reservoir overcharging and lateral flow. Such dynamic processes can be related to conventional lateral Darcy flow as observed in large-scale tilted reservoir units. Dynamic transfers are sometimes called hyper-geopressures.

I) Lateral Transfer

Fluid expansion like geopressure, can also result from a sealed interval having pore fluid pumped into it from another, higher pressure zone. Lateral transfer can generate crestal pore pressures high enough to fracture overlying shale seals, especially when there are long gas columns. The pressure gradient reaches its maximum at the top of the hydrocarbon column, at the highest structural closure and decreases down dip with depth. The geopressure regime tends to be homogenous within the same pressure cell (Traugott, 1996; Bowers, 2002; Yardley and Swarbrick, 2000).

Ii) Hydrofracturing

Dynamic transfers can also be related to vertical hydraulic flow. Hydro-fracturing and open fault zones act as preferential pathways for hydrocarbon migration (Grauls and Cassignol, 1992; Grauls and Baleix, 1993). Such mechanisms can only account for the large volumes of hydrocarbon transferred to shallow depths from deeper sources, in a very short period of geological time. Abnormal fluid pressures are localized within dilatant faults or fracture networks, rather than in the rock matrix itself.

Iii) Reservoir Overcharging

Fluids are vertically and laterally transferred to reservoirs when intersecting faults are discontinuous. Pressure regimes are likely to increase in response to this overcharging (Grauls and Baleix, 1993). The additional pressure value will depend on fluid volume, charging rate, reservoir extension or drainage efficiency, pore and fluid compressibility.

4) Chemical Stress

Chemical stress geopressure mechanisms include smectite to illite transformation (clay diagenesis) and fluid rock interaction.

I) Clay Diagenesis

Smectite is a very common detrital mineral in shales and contains abundant interlayer water in its crystal structure. The water released during simple dehydration is thought to result in geopressures because some of the interlayer molecules are arranged in denser packing than those of ordinary water. Thus, when the interlayer water is expelled to become pore water, there is an expansion in volume and abnormal pressures will result from the density change.

Release of structurally bound water from smectite could also occur during its transformation to illite by the addition of Al and K ions and the release of Na, Ca, Mg, Fe and Si ions plus water. In the Gulf Coast of the United States and even in the Niger Delta, there is a close regional relationship between the onset of geopressures and the smectite to illite transformation (Bruce, 1984, Opara, 2008; Opara et al 2008a,2008b;Opara and Onuoha,2009).Another potential consequence of the mineral transformation from smectite to illite is the sealing effect produced by the release of Si, Ca, Fe, and Mg ions. Boles and Franks (1979) suggested that the ions released from the shales could migrate into adjacent sandstone and precipitate quartz, chlorite, ankerite, and calcite cements. This could potentially cause cementation at the shale – sand contact and help retain pore waters within the shales.

Several authors (Hower, 1981; Pytte and Reynolds,1989) indicate that the main compositional and structural changes in the illite/smectite burial diagenetic sequence are: an increase in illite layers, an increase in interlayer potassium and an increase in the amount of aluminum substituted for silicon in the tetrahedral layer; an release of Mg^{2+}, Fe^{2+}, Ca^{2+},Si^{4+},Na^{+} and water. The released water can make less or equal to thirty five percent (≤35%) of the volume of the smectite crystallite (Petty and Hower, 1972).

Ii) Fluid – Rock Interaction

These include gypsum-to-anhydrite transformation and mineral diagenesis without dehydration. The temperature-controlled reaction of gypsum transforming to anhydrite results in the loss of 39% bound water by volume and is thought to be an important mechanism in generating geopressure in evaporite sections. The primary controls on the reaction are the activity of water in the pore fluid and pressure. The reaction will occur at 40-60^{0}C and potentially can generate fluid pressure significantly in excess of overburden pressure at 1.0km depth (Jowett et al., 1995). Because the reaction occurs during shallow burial, it is unlikely to be responsible for geopressures that occur at great depth.

Similarly, destruction of the porosity of a rock during burial can be accomplished by cementation, as well as by compaction. In a closed system, the growth of cement in the pores of a rock reduces the pore volume and potentially increases pore fluid pressures. As cementation reduces pore space, a link between diagenesis and geopressure seems possible.

6) Other Generative Mechanisms

Apart from the mechanisms listed above, other sources of geopressures are osmosis, artesian effect, buoyancy and inflationary overpressures

I) Osmosis

Large contrast in the brine concentrations of formation fluids across a semi-permeable membrane can induce transfer of fluids across the membrane, from fresh water (dilute solution) to saltier water (concentrated solution). Due to electrical restrictions, water is able to cross the membrane, while anions and cations are excluded. Marine and Fritz (1981) suggested that osmotic pressure could be an explanation for some geopressured sections. The principal argument against this mechanism having anything but very local importance is the requirement for recharge of the more saline water and discharge of the originally less saline waters to maintain the pressure. In addition, brines in geopressured zones tend to be of a lower salinity than adjacent normally pressured brine, which would act to reduce the pressure in the overpressured zones. Osmotic processes could produce significant geopressures only if shales functioned as near perfect membranes.

ii) Hydrocarbon Buoyancy

All gases and most oils have a lower density than the associated formation waters and therefore have a lower pressure gradient. Because overpressure is the excess pressure above hydrostatic for a given depth, there is always some amount of geopressure wherever a column of oil or gas is present. The amount of geopressure is a function of the contrast in the pressure gradients (density differences) of oil, gas and water and the height of the hydrocarbon column. In the North Sea, the maximum geopressure that could be generated by this mechanism is only about 600psi (4.0Mpa).

This mechanism requires a closed system to be effective; if water can escape from the rock, the amount of pressure created could be negligible. This mechanism can create geopressure only because gas density decreases as temperature decreases, thus the bubble tries to expand as it rises to the top of reservoir, but cannot increase its volume due to the incompressibility of the surrounding fluid. Oil would not produce a similar effect because it becomes denser and shrinks in volume as temperature decreases.

Iii) Artesian Effect

The hydraulic head resulting from elevation of the water table in highland regions exerts a pressure in the subsurface if the reservoir or aquifer is overlain by a seal (Bachu and Under Schultz, 1993). Wells drilled into the overpressured aquifer are known as artesian wells and produce water to the surface due to the excess pressure. The potentiometric head is measured either as the vertical height of the water table above datum (the practice in hydrogeology) or as the height converted to pressure with knowledge of the formation fluid density.

Lateral continuity of reservoirs over long distances beneath a continuous seal is required for this mechanism to operate. The amount of overpressure cannot exceed the height of the elevated water table. In many of the interior basins of the Central United States basin and Range Province, conditions are right for generating significant amounts of overpressure by this mechanism.

IV) Inflationary Geopressures

Inflationary overpressures are either generated late in the burial history or as a result of fault enabling pressure communication between previously isolated compartments (Indrelid,1997;Krusi, 1994).In either case, there is an increase in the fluid pressure producing a sudden reduction in vertical effective stress. In this case, the maximum vertical effective stress experienced by the rock is likely to have occurred before the onset of overpressures. Inflation can occur in all geopressured settings from Tertiary deltas to ancient rift settings such as the North Sea. In cases of inflationary geopressure, the rock properties are set by the maximum vertical effective stress, which occurred prior to late geopressuring. In this case reservoir porosity can be expected to be similar to that predicted from simple porosity depth graphs.

DISCUSSION

Based on an empirical relationship between geopressure gradient, permeability and deposition rate, compaction disequilibrium was deduced to be the dominant mechanism for observed fluid geopressure in the Gulf of Mexico and the North Sea(Mann and Mackenzie ,1990). Swarbrick and Osborne (1998), proposed that the major mechanisms for large magnitude geopressure in most extensional sedimentary basins are compaction disequilibrium due to rapid loading in fine grained sequences, and fluid volume expansion during gas generation).Despite the arguments for compaction disequilibrium (generally undercompaction) being the cause of geopressure in many basins, a lot of evidence has also been gathered that may suggest otherwise. Luo and Vasseur (1992) presented an argument that the excess pressure is so great that it cannot be explained by compaction alone in some areas, such as the United States' Gulf Coast. Hunt et al. (1998), stated that fine grained quartz and carbonates stop compacting at porosities around 3%, whereas shales containing minerals with large surface areas, such as smectite and illite, stop compacting at porosities around 10%. Bradley (1975) and Swarbrick (1995) suggested that excess pressure would dissipate once burial slows to a rate at which fluid loss matches the addition of overburden stress. They maintained that hydrocarbon generation is the most important mechanism within source rocks based on a comparison of the depth of the oil window and the top of the geopressured zone. Similarly, Surdam et al, (1997) proposed that gas generation and accumulation are the likely origin for the geopressure in reservoirs sealed by clay. Most researchers agree that gas generation should be accompanied by a large volume expansion; therefore, this mechanism clearly has the potential to be a major factor in overpressuring. Fluid expansion mechanisms have been proposed by various authors to be a dominant factor in geopressure generation worldwide(Burrus et al ,1993; Ward,1995; Bowers ,1995, 2000, 2002, and Alnes and Lilburn (1998). Unlike undercompaction, fluid expansion can cause the pore pressure to increase at a faster rate than the overburden stress which forces the effective stress to decrease as burial continues. These mechanisms are thought to generate the extreme geopressures, which approach or even exceed the fracture gradient in most sedimentary basins. The extreme geopressures observed at depth in many basins coincide with the time temperature related fluid expansion mechanisms, hydrocarbon generation and smectite–to-illite diagenesis. There is also an established relationship between increasing temperature gradient and depth to extreme geopressures in many worldwide basins, which supports this contention (Ward, 1995; Bowers, 1995; 2002; Alnes and Lilburn, 1997; 1998; Miller and Luk, 1993; Bowers and Katsube, 2002;Opara, 2008).

CONCLUSION

In young Tertiary sequences like the Gulf of Mexico, Niger Delta, etc, compaction disequilibrium and fluid expansion mechanisms are actually the dominant causes of geopressures. Most traditional pore pressure and basin models have assumed disequilibrium compaction to be the sole pressure generating mechanism. By not accounting for other pressure generating mechanisms they become physically incorrect and require trend-line shifts to match formation pressures (Ward, 1995; Burrus et al ,1993).These models should therefore be reviewed and upgraded to incorporate other dominant sources of overpressures in other to properly model source rock maturation and migration of hydrocarbons.

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