One-Two-Three, What Do We See

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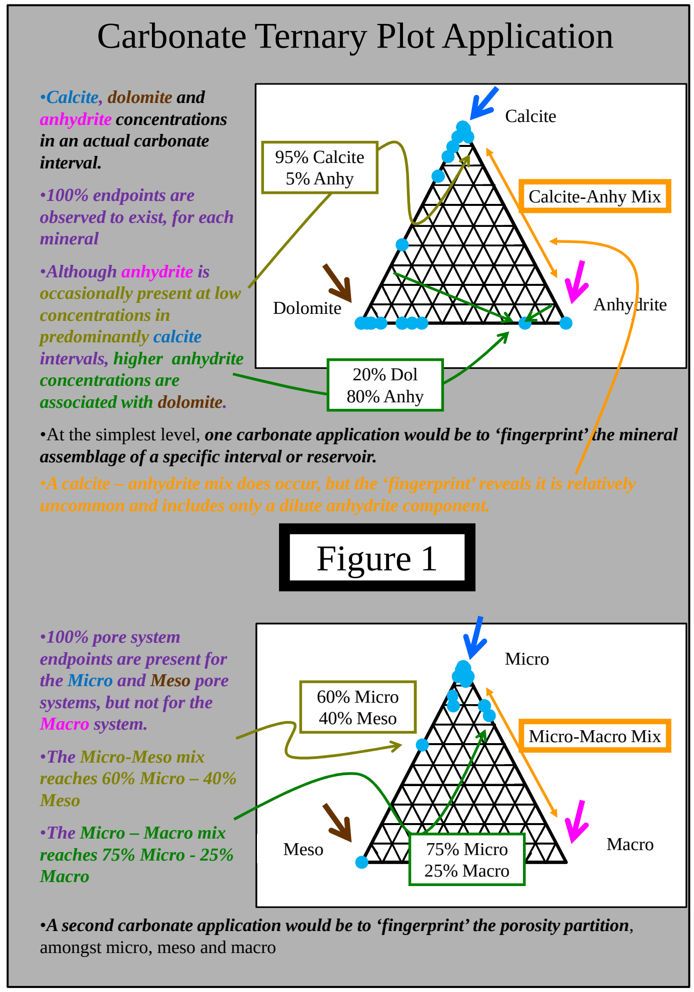
In today's world of powerful laptop computers and visualization software, ***geoscientists routinely produce and rotate three dimensional graphics as a part of the interpretation process. Hardcopy documentation, however, remains vital and is in two dimensions.***



Here, ***the ternary plot fills a niche***, somewhat similar to (but more sophisticated than) the histogram, in that it ***summarizes the relative simultaneous values of three components*** (whereas the histogram summarizes a single attribute) in a two dimensional format. The display ***may additionally serve as a kind of Quick Look Fingerprint that allows one to visually recognize similar three dimensional combinations***: Figure 1.

As carbonate petrophysicists, ternary plot applications include (but are not limited to);

1. Relative concentrations and relationships of three mineral assemblages (for example calcite, dolomite, anhydrite),
2. Bulk volume porosity – mineralogy relations (porosity, calcite, dolomite),
3. Porosity partitions (micro, meso, macro).

Today's spreadsheets are capable of producing ternary diagrams, and so ***with an understanding of how to implement and utilize this display technique, we are able to add this capability to our spreadsheet toolbox*** (which includes both differential and statistical error analysis, capillary pressure curve fitting, and much more).

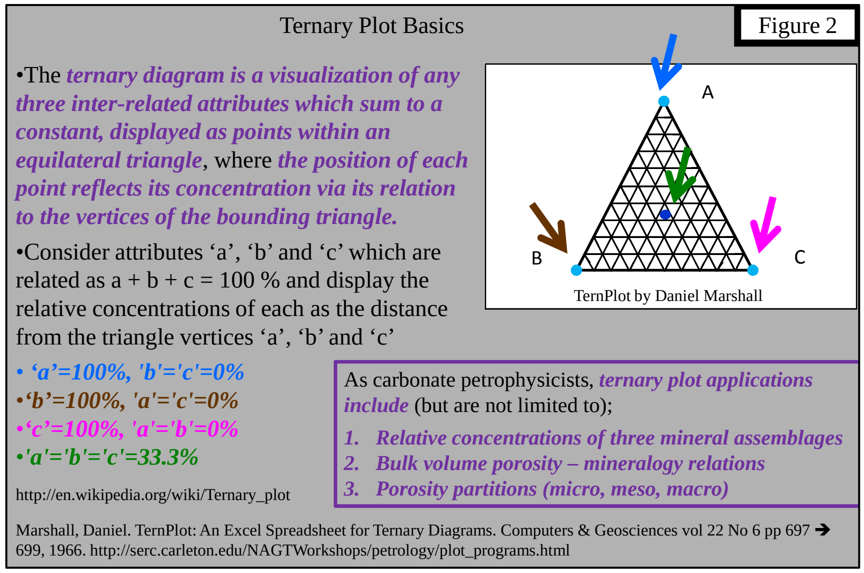
Ternary Plot Basics

The ternary diagram is a visualization of any three inter-related attributes which sum to a constant. If, for example, the mineral assemblage in a formation of interest consists of calcite, dolomite and anhydrite, the volumetric sum is 100%, and if any two concentrations are known, so is the third: Figure 2.

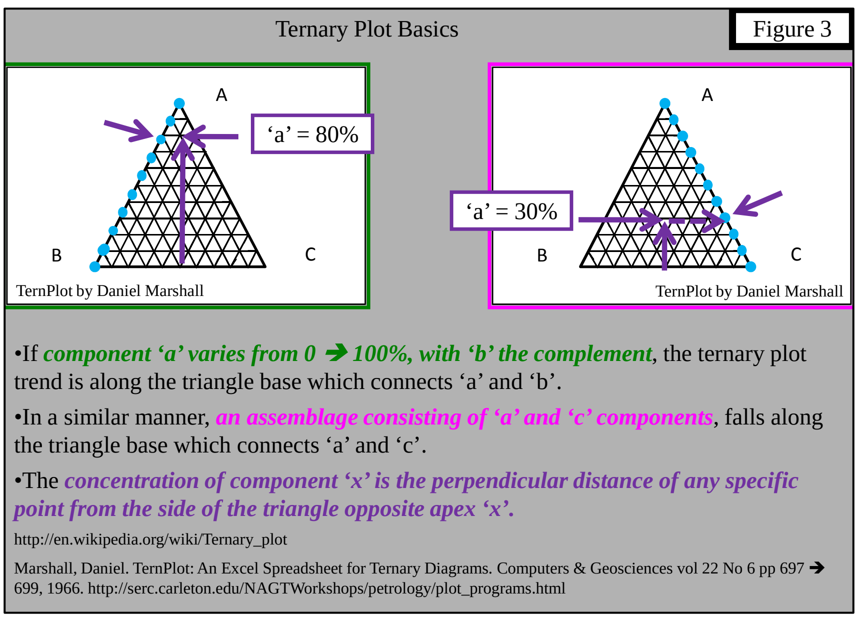
The actual ***distribution is displayed as points within an equilateral triangle, where the position of each point reflects its concentration via its relation to the vertices of the bounding triangle.***

Consider, for example, attributes ‘a’, ‘b’ and ‘c’ which are related as a + b + c = 100 % and display the relative concentrations of each as the distance from the triangle vertices ‘a’, ‘b’ and ‘c’ for the following distributions.

1. ‘a’=100%, ‘b’=’c’=0%
2. ‘b’=100%, ‘a’=’c’=0%
3. ‘c’=100%, ‘a’=’b’=0%
4. ‘a’=’b’=’c’=33.3%



Each side of the equilateral triangle represents a concentration of 0% for one of the assemblages, and the apex opposite represents 100% for that same component.



If, for example, component ‘a’ varies from 0 → 100%, with ‘b’ the complement (calcite ⇔ dolomite assemblage), the ternary plot trend is along the triangle base which connects ‘a’ and ‘b’. In a similar manner, an assemblage consisting of ‘a’ and ‘c’ components, falls along the triangle base which connects ‘a’ and ‘c’.

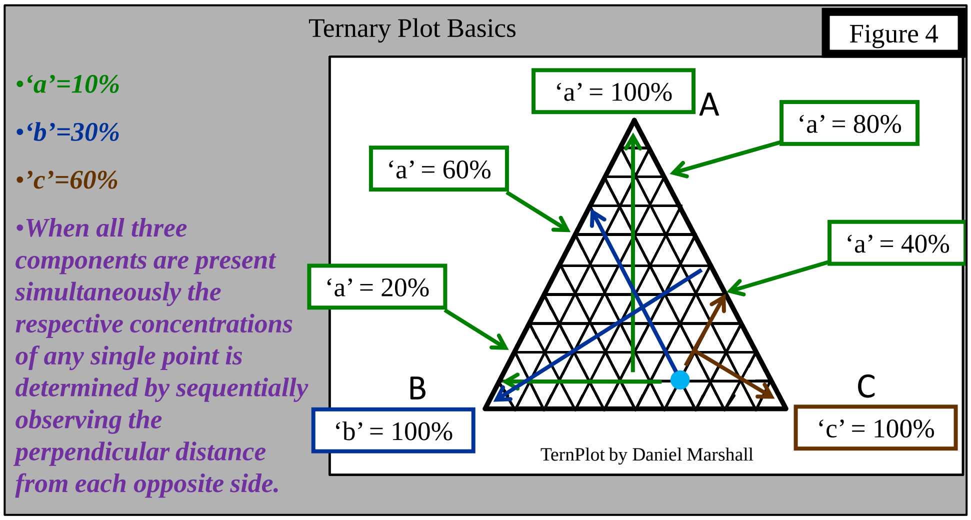
The concentration of component ‘x’ is the perpendicular distance of any specific point from the side of the triangle opposite apex ‘x’: Figure 3.

When all three components are present simultaneously (‘a’=10%, ‘b’=30%, ’c’=60%)***, the respective concentration of any single point is determined by sequentially observing the perpendicular distance from each opposite side:*** Figure 4.

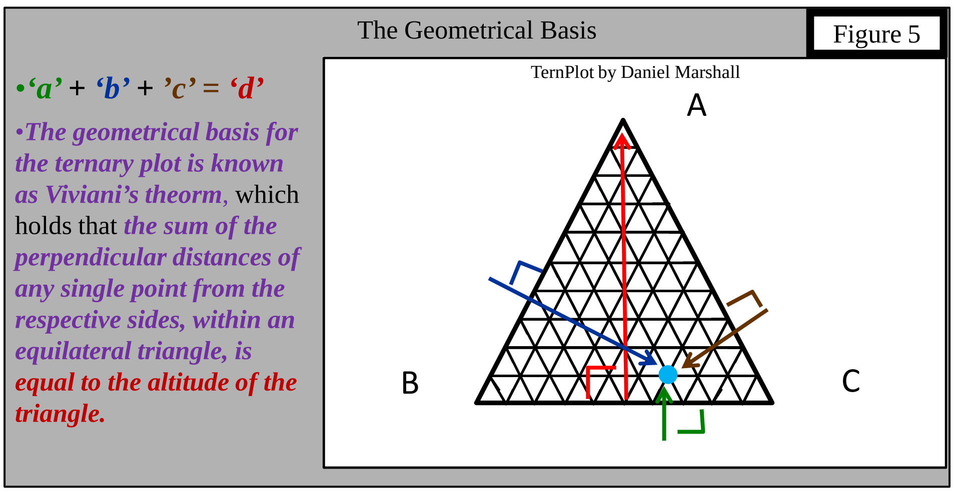
Ternary plots have a variety of oilfield applications, with just a few being;

1. Okasha et al (2001) use the ternary diagram to illustrate ***variations in wettability*** for a heterogeneous carbonate formation,
2. Prada et al (2001) characterize ***well intervention options*** and

3. Dutton et al (2010) ***classify Wilcox sand*** with a ternary display.



Not surprisingly, ***the technique has many applications in science, and may be extended beyond the above three component discussion***. The cations and anions present in water, for example, may be displayed in individual ternary plots, leading to what is known as a Piper diagram. In the petrophysics world, we sometimes display wireline-based ρ_{maa} vs U_{maa} in a triangular format for mineral assemblage characterization.



The geometrical basis for the ternary plot is known as Viviani's theorm, which holds that the sum of the perpendicular distances of any single point from the respective sides, within an equilateral triangle, is equal to the altitude of the triangle. ***The concept may be extended to equilateral polygons***: Figure 5.

Carbonate Application

At the simplest level, one carbonate application would be to 'fingerprint' the mineral assemblage of a specific interval or reservoir. The mineral characterization may be accomplished with visual observations, XRD/XRF or (among other options) by wireline log cross-plots.

In this illustrative exhibit (Figure 6, based upon actual carbonate data), we observe all three endpoints (calcite, dolomite and anhydrite) to be present, with the ***primary mixtures being***;

1. ***Calcite ⬄ Dolomite***, corresponding to the points which fall along the calcite – dolomite baseline,
2. ***Dolomite ⬄ Anhydrite***, corresponding to the points which fall along the dolomite – anhydrite baseline.

Although some calcite – anhydrite mix does occur, the 'ternary fingerprint' reveals it is relatively uncommon and includes only a dilute anhydrite component.

A second carbonate application would be to 'fingerprint' the porosity partition, amongst (for example) micro, meso and macro pore systems (Hartmann has a nice discussion and illustration of both carbonate and clastics, within the context of Winland's R35): Figure 7.

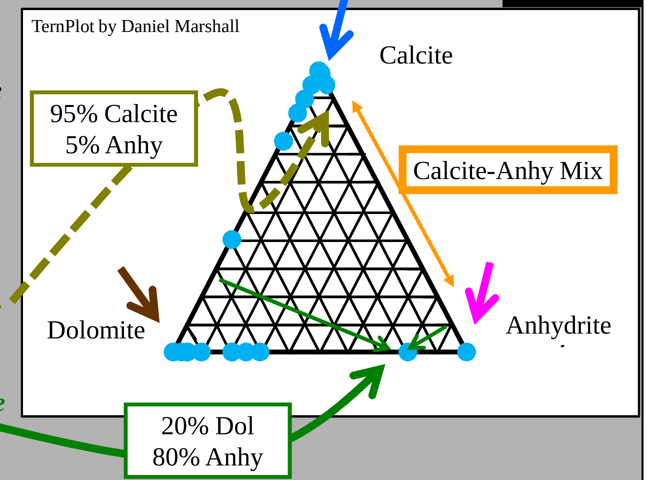
Carbonate Ternary Plot Application

Figure 6

•Calcite, dolomite and anhydrite concentrations across an actual carbonate interval.

•100% endpoints are observed to exist, for each mineral

•Although anhydrite is occasionally present at low concentrations in predominantly calcite intervals, higher anhydrite concentrations are associated with dolomite.



•At the simplest level, ***one carbonate application would a '3-D fingerprint' of the mineral assemblage of a specific interval or reservoir.***

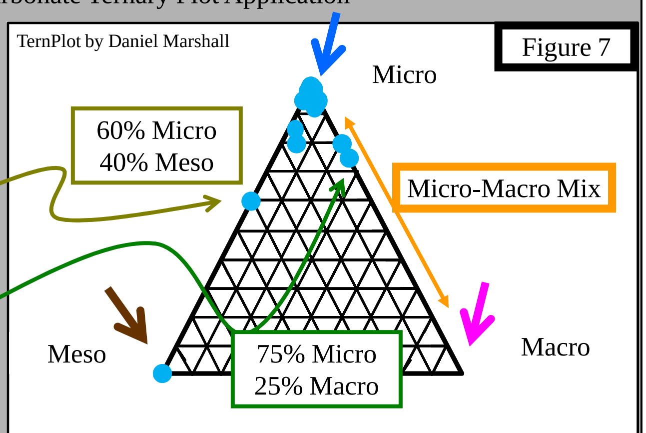
•Although some calcite – anhydrite mix does occur, the 'fingerprint' reveals it is relatively uncommon and includes only a relatively dilute anhydrite component.

Carbonate Ternary Plot Application

•100% endpoints are present for the Micro and Meso pore systems, but not for the Macro system.

•The Micro-Meso mix reaches 60% Micro – 40% Meso

•The Micro – Macro mix reaches 75% Micro - 25% Macro



•At the simplest level, one carbonate application would be to 'fingerprint' the mineral assemblage of a specific interval or reservoir. The mineral characterization may be accomplished with visual observations, XRD/XRF or (among other options) by wireline log cross-plots.

•A second carbonate application would be to 'fingerprint' the porosity partition, amongst micro, meso and macro

In clastics, it may be possible to accomplish the partitioning with only NMR T2 (Romero et al, 2002), in a manner that directly relates to Winland.

In carbonates, however, ***the combination of lower surface relaxivity and a (typically) greater range of pore sizes in carbonates, will often require a combination of both NMR and micro-resistivity images*** (Gomaa et al, 2006). And even then there may be a 'blind spot' between the upper pore size uniquely identifiable with the NMR (specifically vuggy porosity vs large IG/IX pores) and the lower pore size that can be 'seen' with the micro-resistivity. In any case, one makes the best of what they have to work with (and points out to their boss the importance of a skilled petrophysicist being a part of the process), and once again the ternary 'fingerprint' provides a useful visual summary.

Summary

Ternary plots serve several useful functions;

1. ***Two dimensional documentation of three inter-related attributes***, analogous in some regards (but more sophisticated) to a histogram summary of a single attribute,
2. ***Quick look fingerprint characterization*** of water chemistry, mineral assemblages, porosity partitions (micro, meso, macro), etc.

Ternary plots may be produced with modern spreadsheets, and so ***with an understanding of how to create and interpret this display, we may add this capability to our spreadsheet toolbox***.

Useful ternary plot www sites include (but are not limited to)

Marshall, Daniel. TernPlot.
http://serc.carleton.edu/NAGTWorkshops/petrology/plot_programs.html
Ma, Weifeng and Xiaorui Wang. GCDPlot.
http://sourceforge.net/projects/gcdplot/
Niu, Yaoling. Template for ternary plots.
http://serc.carleton.edu/NAGTWorkshops/petrology/plot_programs.html

Acknowledgement

As a 17 year old in Army Boot Camp some 44 years ago, I came to meet and ultimately respect an unexpected individual: Drill Sergeant Herb Rettke. At a time when drill sergeants had near unquestioned authority, Herb realized that the best training was accomplished with individually-specific motivation. And in an era when racial profiling was not unusual, Herb was color blind.

In 1966 Herb had already served his country as an infantryman in an earlier war, and he would go on to serve two additional infantryman tours in a second war. In the years to come as I observed oil company management leave the night/weekend/holiday duty to their underlings, while they enjoyed their time off, it struck me that their version of 'walk the talk' was very different than Herb's.

In Y2003 I was able to find Herb (via Google) living only 250 miles from me, and we have visited a number of times since. If a stranger were to meet Herb today, their immediate impression would be 'a kindly grandfather type', and they would never realize his sincere devotion to his country. This brought to mind another experience. As a university physics instructor, I repeatedly observed that the best exam scores were seldom made by the people who dominated the classroom conversation.

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Biography

R. E. (Gene) Ballay's ***34 years in petrophysics*** include ***research and operations*** assignments in Houston (Shell Research), Texas; Anchorage (ARCO), Alaska; Dallas (Arco Research), Texas; Jakarta (Huffco), Indonesia; Bakersfield (ARCO), California; and Dhahran, Saudi Arabia. His carbonate experience ranges from individual Niagaran reefs in Michigan to the Lisburne in Alaska to Ghawar, Saudi Arabia (the largest oilfield in the world).

He holds a ***PhD*** in ***Theoretical Physics*** with ***double minors in Electrical Engineering & Mathematics***, has ***taught physics in two universities***, ***mentored Nationals*** in Indonesia and Saudi Arabia, published ***numerous technical articles*** and been designated ***co-inventor on both American and European patents***.

At retirement from the Saudi Arabian Oil Company he was the senior technical petrophysicist in the Reservoir Description Division and had represented petrophysics in three multi-discipline teams bringing on-line three (one clastic, two carbonate) multi-billion barrel increments. Subsequent to retirement from Saudi Aramco he established Robert E Ballay LLC, which ***provides physics - petrophysics consulting services.***

He served in the US Army as a Microwave Repairman and in the US Navy as an Electronics Technician, and he is a USPA Parachutist and a PADI Dive Master.

