Gaffney Cline

E&P Opportunity Screening - Gross Rock Volume Calculation Methods

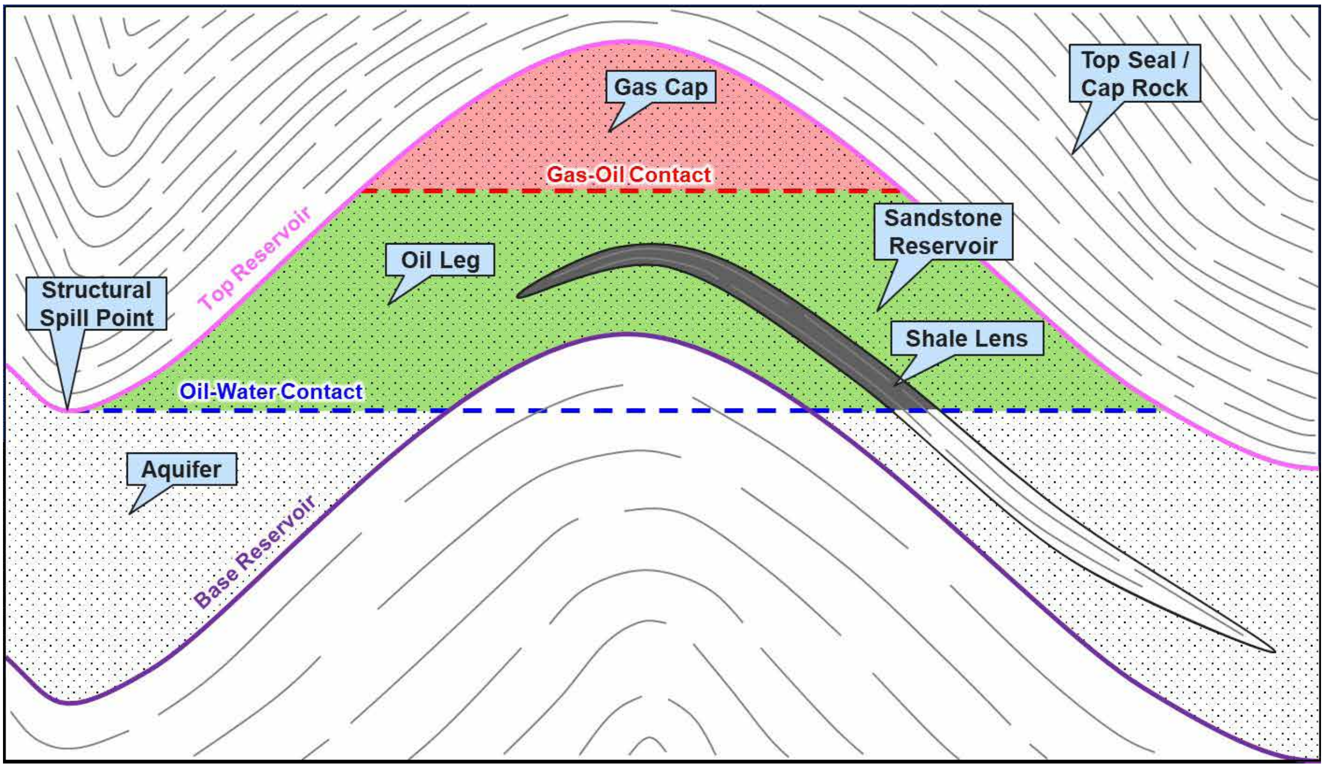
Introduction

Gross Rock Volume (GRV) is often the most impactful variable in hydrocarbon resource estimation. There are many possible methods to estimate GRV, each with benefits and limitations related to the geological setting, data type and quantity and time available. Here, GaffneyCline considers the importance of GRV before presenting three commonly used GRV estimation methods, commenting upon their appropriate use, assessing their relative accuracy and suggesting scenarios to optimise the efficiency of in-place volume evaluation by the pragmatic application of the appropriate methodology.

GRV and its Place in HCIIP Calculation

GRV (or Bulk Rock Volume) is the principal and often most significant input to the calculation of in-place hydrocarbon volumes (HCIIP). Put simply, GRV is the volume of rock beneath the top seal of the reservoir interval down to the base of the reservoir interval or the hydrocarbon-water contact, whichever is shallower. Between these bounds however, this volume is inclusive of everything, including the solid rock matrix, non-reservoir units, cements and pore space. Figure 1 is a cartoon of an antiformal hydrocarbon trap with the areas collectively comprising the GRV containing a colour fill.

Figure 1: Cartoon Cross-section through an Antiformal Hydrocarbon Trap



To calculate HCIIP a formula is used (Figure 2) which includes additional parameters in addition to GRV. These include Net-to-Gross (NTG) which removes non-reservoir from the GRV, Porosity which removes everything except the pore space where any fluid is stored and Hydrocarbon Saturation which removes any water, to leave the volume of hydrocarbons contained within pore space. A Formation Volume Factor (FVF) is then applied that accounts for the difference in volume of the hydrocarbon fluid at surface conditions relative to subsurface conditions. FVF is expressed as a shrinkage of an oil volume as a consequence of gas leaving solution, and the expansion of a subsurface gas volume due to the effect of reducing pressure and temperature. Finally, unit conversion is commonly required to get the required units, which will vary depending upon the GRV measurement and the required output volumes.

Figure 2: Hydrocarbon Initially In-Place Formula

$$HCIIP = \frac{GRV \times NTG \times Ø \times S_{HC}}{FVF}$$

Where:

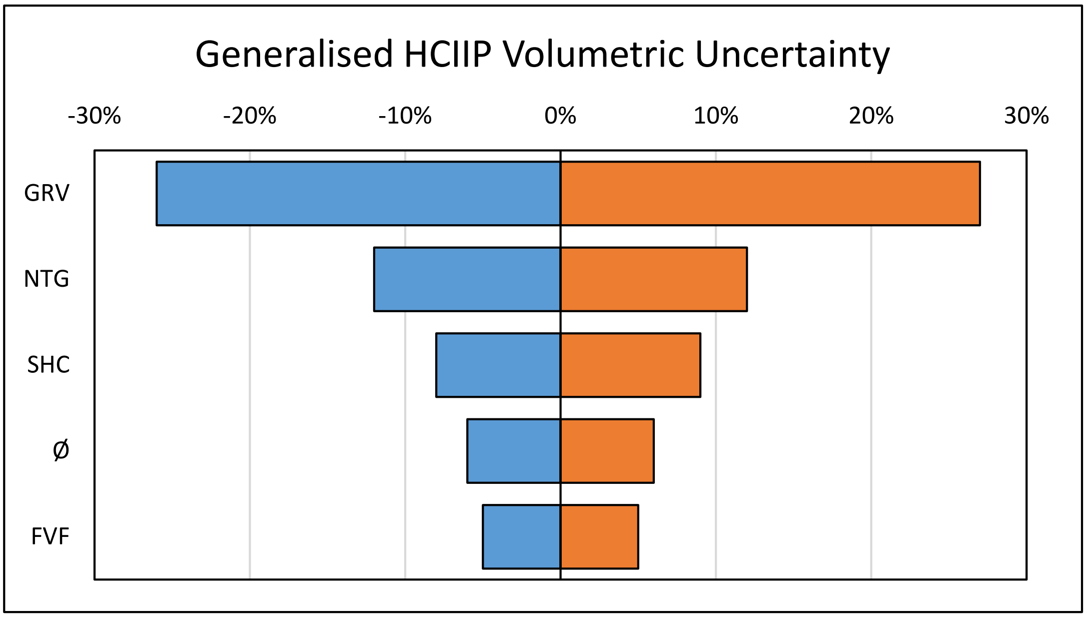
GRV = Gross Rock Volume (m3, ft3, Ac-ft)
NTG = Net-to-Gross (%)
Ø = Porosity (%)
S_{HC} = Hydrocarbon Saturation (%)
FVF = Formation Volume Factor (Reservoir Volume/Surface Volume)

GRV and its Place in HCIIP Calculation

GRV is a combination of three main factors, each of which are often subject to significant uncertainty. The first is subsurface structural geometry (area) of the reservoir unit, which is often determined from a combination of well and seismic data with uncertainty associated with both the seismic interpretation and time-to-depth conversion. The second is the thickness of the gross reservoir interval, which is commonly determined from a combination of seismic and well data. Lateral thickness variation is subject to both depositional and post-depositional processes and is commonly determined through data with complete spatial coverage such as 3D seismic data and/or geological concept.

The degree of uncertainty associated with the gross reservoir thickness is dependent on data density, e.g. number of wells, geological complexity and limitations in seismic resolution. The last factor is the depth to and lateral variability of hydrocarbon-water contacts, which can be accurately determined in data-rich environment through analysis of a combination of wireline logging, formation pressure data and seismic data. However, in exploration or appraisal phases of a hydrocarbon discovery where limited well data are available, the definition of the depth of hydrocarbon contacts are often subject to considerable uncertainty. Further to this, the presence of transition zones, structural or stratigraphic compartmentalization and tilting of contacts through hydrodynamic trapping add to the uncertainty. This means that often the uncertainty range in the GRV dominates the uncertainty range in the ultimate HCIIP volume estimates (Figure 3).

Figure 3: Generalised Tornado Chart showing HCIIP Volumetric Uncertainty of a Hydrocarbon Field



Estimation Methods

Multiple methods to calculate GRV are available, ranging from 'back-of-the-envelope' map-based approaches through to comprehensive and time-consuming approaches using state of the art subsurface modelling software.

Below three common types of GRV estimation process are reviewed. The methods described by no means provide a complete review of available nor robust methods, but cover a range of methods, which span the spectrum from high-level (quick-look) review through to detailed assessment.

Map-based Approach

The map-based (or slab) approach consists of the sum of three parameters, namely areal extent of hydrocarbon trap, gross reservoir thickness and geometric correction factor (or shape factor). The geometric correction is required, as the volume estimated by multiplying the gross reservoir thickness by areal extent of the hydrocarbon trap invariably is an over-estimate of GRV as a result of the wedging geometry on the flank of the structure where the dipping reservoir surface intersects the hydrocarbon-water contract.

Geometrical Correction

In the Map-based approach, geometrical correction is a necessary step in ensuring results are comparable to more in depth estimation approaches. As previously described, the geometric correction factor accounts for the intersection of the dipping reservoir surface towards the hydrocarbon-water contact results in a peripheral wedge of rock volume which is less than the thickness of the gross reservoir. The method of geometrical correction calculation can be derived from long-standing geometrical relationships, such as the matrix derived by White in 1987 (Figure 4).

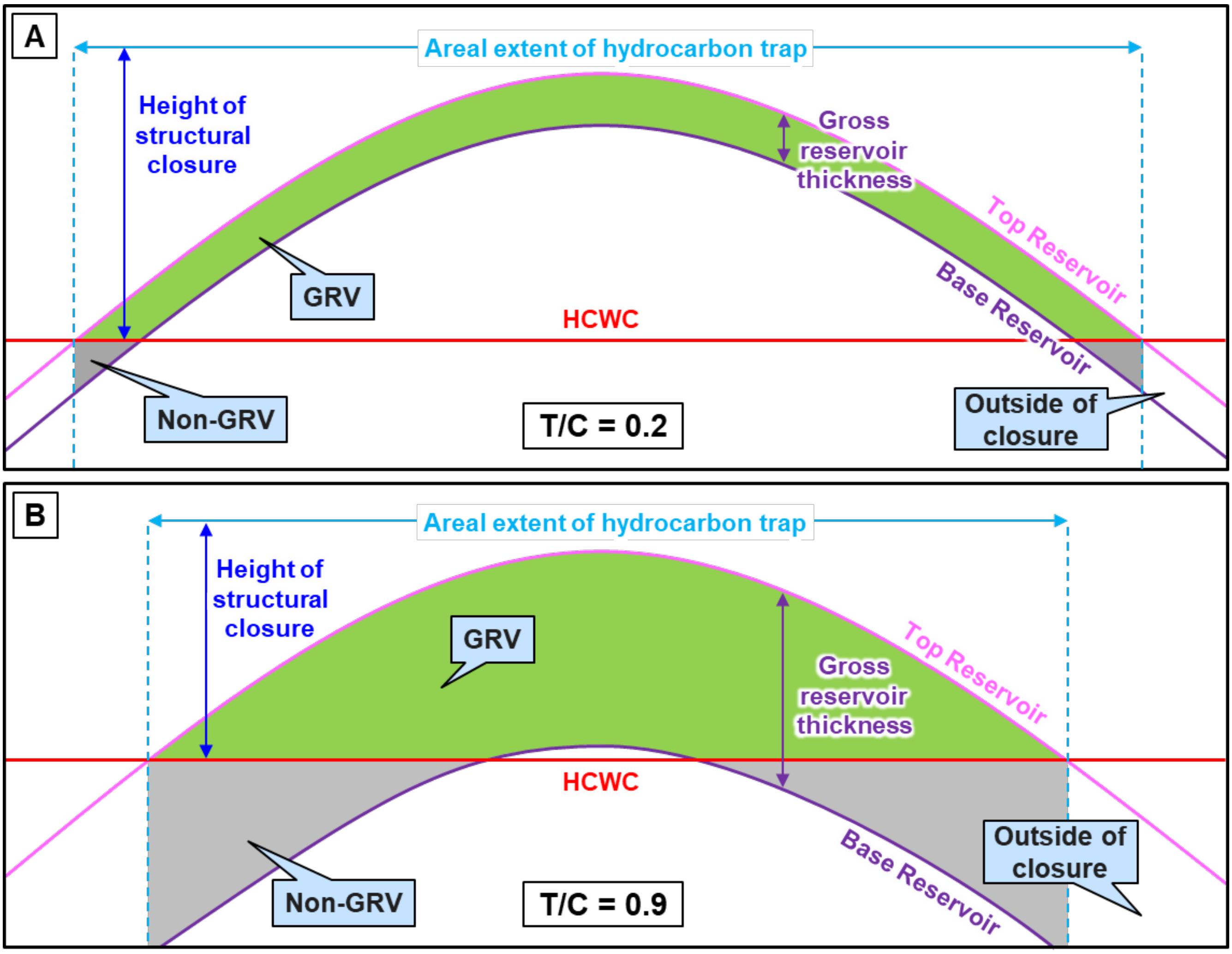
Figure 4: Geometric Correction Factor Matrix, after White, 1987

		Length/Width		
		1	2	10
Thickness/Closure	≥1.0	0.34	0.42	0.49
	0.9	0.37	0.46	0.54
	0.8	0.41	0.51	0.60
	0.7	0.47	0.56	0.66
	0.6	0.53	0.61	0.71
	0.5	0.59	0.67	0.76
	0.4	0.66	0.73	0.81
	0.3	0.74	0.80	0.86
	0.2	0.83	0.87	0.91
	0.1	0.92	0.94	0.96
	0.0	1.00	1.00	1.00

A matrix such as White's provides a simple correction factor between 0.34 and 1.00 for an antiformal structure based upon the relationship of two measurable parameters. The first, Thickness/Closure (T/C) is a value between 0 and 1, and is calculated by taking the gross reservoir thickness and dividing it by the height of the structural closure (or hydrocarbon column height). The second parameter, Length/Width (L/W) is essentially a measure of elongation. L/W records a value between 1 and 10 and results from dividing the length of the structure by its width. There is technically no limit to the degree of elongation which can be achieved, however a structure with a L/W of 10 represents a reasonable maximum for most geological circumstances.

Structural traps requiring the most significant geometric correction factor (reduction of GRV) are those where the gross reservoir thickness is significant (or greater) compared to the height of structural closure (example B in Figure 5) in addition to where trap elongation ratio is small. The reason for this is that the controlling factor of the GRV is predominantly the hydrocarbon-water contact and therefore a greater amount of correction is required to account for the fact that a significant proportion of the gross reservoir interval lies within the water column. In instances where the gross reservoir thickness exceeds the height of the structural closure, the base reservoir plays no role in the calculation of GRV. There is therefore no requirement for the T/C values to exceed 1 in the matrix. The elongation of the trap is impactful upon the geometric correction factor, as a dome structure has a greater degree of curvature defining its edge than an elongate anticline. Of the two controlling parameters however the relative impact of the T/C is considerably greater than L/W.

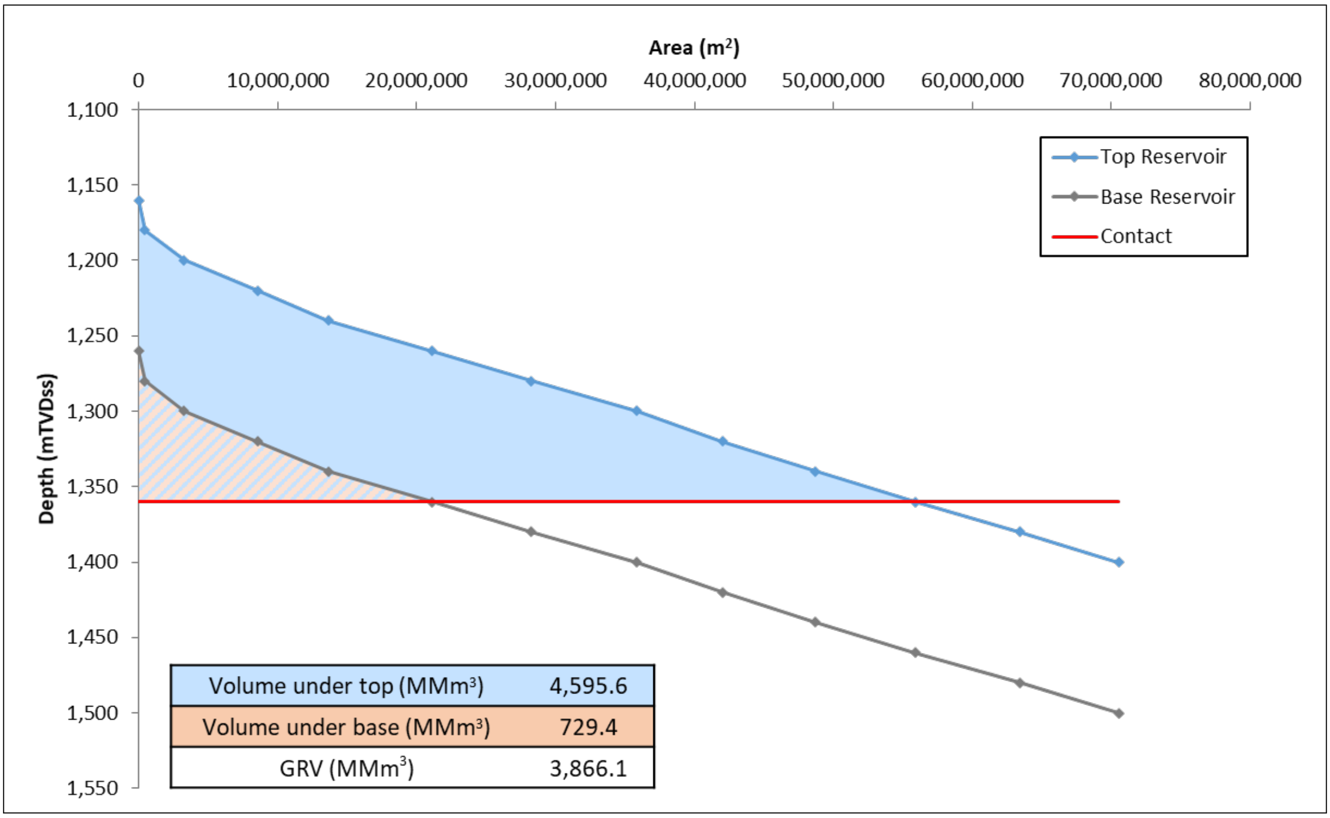
Figure 5: Cartoon of T/C Relationship in an Antiformal Trap



Area-depth Approach

The area-depth approach uses the relationship between area and depth of a given structure to estimate a volume. This approach often requires the use of a relatively simple spreadsheet or software, which calculates and subtracts the volume between the base of the reservoir and a fluid contact from the top of the reservoir and a fluid contact, leaving the GRV (Figure 6). This method allows GRV to be quickly determined for a range of areas and depths allowing multiple scenarios to be evaluated. The ability to use different geometries for the top and base of the reservoir interval means that simple stratigraphic GRV estimates can be generated.

Figure 6: Area-depth Approach Example



Geocellular Approach

The Geocellular model approach directly calculates GRV based upon three dimensional surfaces or grids, which represent the reservoir surfaces and fluid contacts in the subsurface. This is equivalent to the structural grid element in generation of a static reservoir model, but does not require any facies or property modelling components to be undertaken. This approach requires the use of specialist subsurface software, which is able to perform the necessary calculations.

In a data rich environment, where time and resourcing allows, it is industry best practice and strongly recommended that this approach be undertaken, as it enables accuracy of estimates through incorporation of all available data.

Applicability

The applicability of these different estimation methods varies depending upon both the geological and project setting. In terms of the geological setting, both the Map-based and Area-depth approaches are designed for use with structural trapping mechanisms, and as such any trapping mechanisms with a stratigraphic component or a complex structural trap which deviates significantly from idealised geometries are likely to be considerably less accurate. The reason for this is that traps with a dominant stratigraphic component often are not geometrically predictable and therefore the estimation of a geometric correction factor or average gross reservoir thickness is subject to significant uncertainty. The more robust geocellular model approach in comparison is able to handle traps of significantly more geological complexity, at the cost of additional time taken to undertake GRV calculation. In terms of the project setting there are certain circumstances where time, resources or data are limited and as a consequence undertaking a more rudimentary GRV estimation approach may offer a pragmatic solution. Such circumstances are M&A projects, portfolio ranking, internal QC and Reserves and Resource auditing. Table 1 summarises the relative benefits and limitations of each of the described GRV estimation methods.

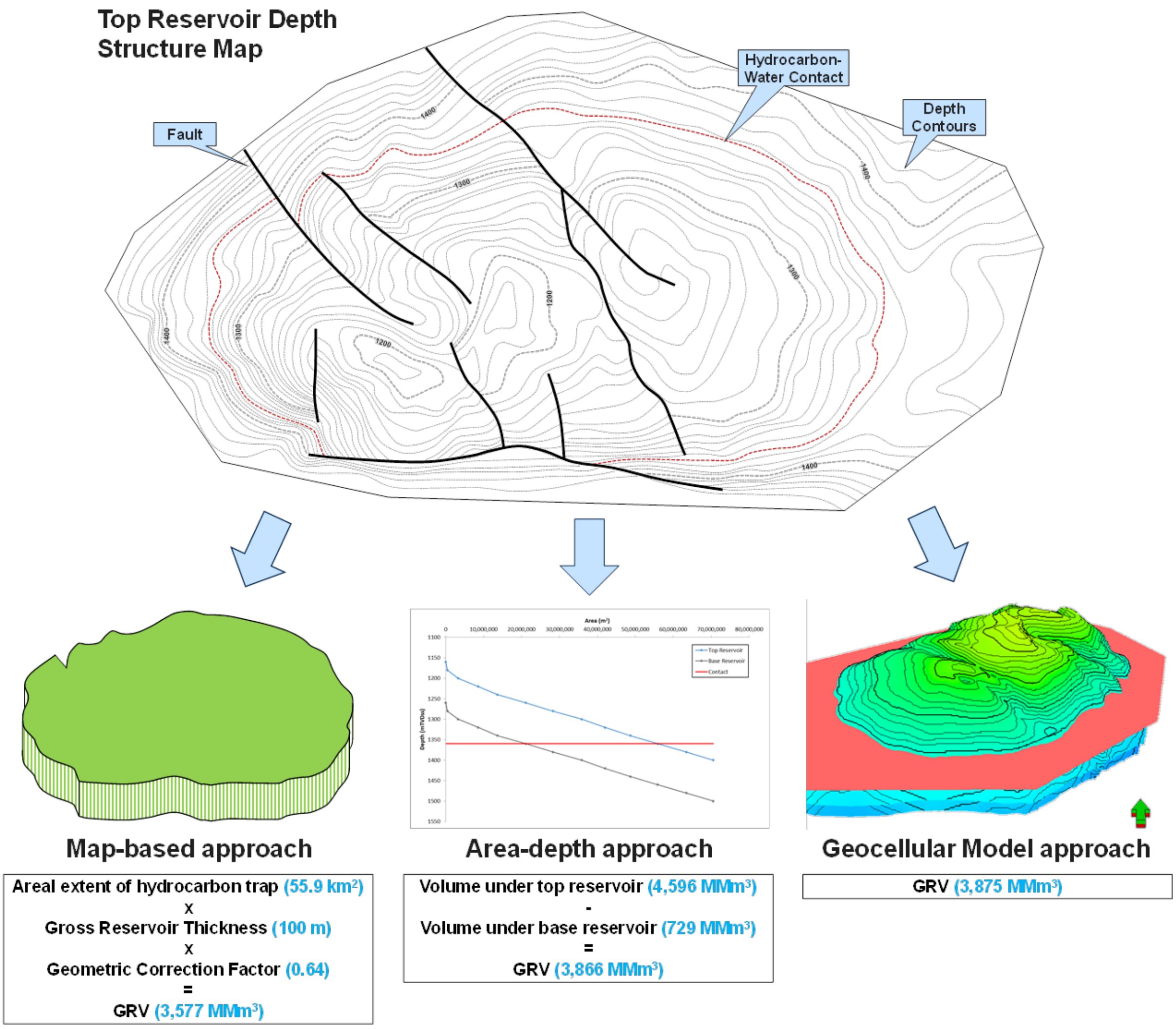
Table 1: GRV Estimation Method Benefits and Limitations

GRV Estimation Approach	Map-based	Area-depth	Geocellular
Calculation time	Minutes to hours	Hours	Days to weeks
Require specialist software?	No	No / Yes	Yes
Able to calculate GRV of complex structural and stratigraphic traps?	No	No / Yes	Yes

Comparison of Methods

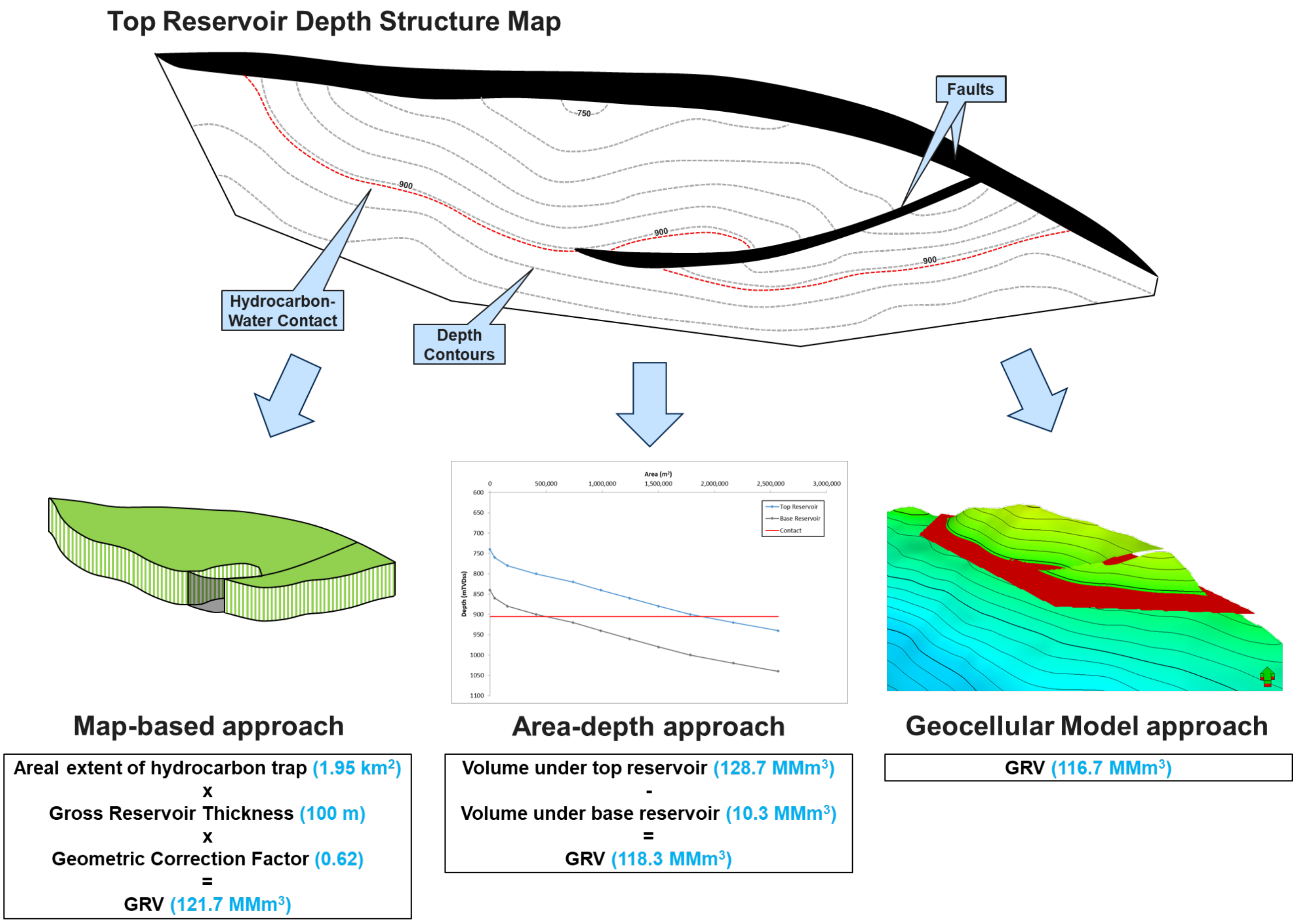
Figure 7 shows an example of the three GRV estimation methods in use for a real-world example of a faulted and east-west elongated antiform structure. Such a structure is an ideal candidate for all three estimation methods, which is shown by the comparable GRV estimates, with a percentage difference of less than 8% compared to the geocellular model approach.

Figure 7: GRV Estimation Methods in Antiformal Structure



As a sensitivity on the robustness of the approaches in different common geological scenarios, GaffneyCline calculated GRV for a real-world example of a footwall trap with a three-way dip closure (Figure 8). Such a structure deviates from an idealised geometry and as such it would be expected for the difference to be greater. However, the results show an acceptable degree of similarity in the results and are less than 5% different to the geocellular model approach GRV. It must be noted that the surfaces generated for this sensitivity assume vertical faulting and conformable reservoir thickness, which is a simplification of most geological circumstances. Despite this, it is clear that given appropriate caution in application, the alternative approaches remain functional for a high-level approximation of GRV.

Figure 8: GRV Estimation Methods in Footwall Structure



GaffneyCline continued this assessment by calculating GRV using all three estimation approaches for both trapping geometries and changing the gross reservoir thickness, which in turn varies the T/C element. The results of these sensitivities are shown in Table 2. It is clear that for both trapping geometries, both the map-based and area-depth GRV estimation methods give results less than 8% different to the geocellular model approach. The map-based approach is the most different, with an average difference of around 6% for both trapping geometry types, whilst the area-depth approach gives negligibly different GRV estimates in the antiformal structure and around 2% in the footwall trap.

Table 2: GRV Estimates from all Three Estimation Approaches

Example		Model GRV (MMm^3)	Gross Res. Thick. (m)	Height of Closure (m)	T/C	L/W	Shape Factor	Area (km^2)	Map-Based GRV (MMm^3)	% Diff.	Area-Depth GRV (MMm^3)	% Diff.
Anticline	A	1,047.4	20	181	0.11	1.90	0.93	55.89	1,043.0	-0.4%	1,045.9	-0.1%
	B	1,956.0	40	181	0.22	1.90	0.86	55.89	1,913.8	-2.2%	1,953.0	-0.2%
	C	2,732.8	60	181	0.33	1.90	0.78	55.89	2,612.5	-4.4%	2,731.5	0.0%
	D	3,376.7	80	181	0.44	1.90	0.71	55.89	3,156.9	-6.5%	3,372.4	-0.1%
	E	3,875.5	100	181	0.55	1.90	0.64	55.89	3,577.2	-7.7%	3,866.1	-0.2%
	F	4,220.8	120	181	0.66	1.90	0.58	55.89	3,890.2	-7.8%	4,214.0	-0.2%
	G	4,441.9	140	181	0.77	1.90	0.53	55.89	4,108.2	-7.5%	4,436.1	-0.1%
	H	4,561.4	160	181	0.88	1.90	0.47	55.89	4,203.2	-7.9%	4,554.3	-0.2%
	I	4,593.8	180	181	0.99	1.90	0.42	55.89	4,265.8	-7.1%	4,591.3	-0.1%
	J	4,594.7	200	181	>1	1.90	0.42	55.89	4,249.0	-7.5%	4,595.6	0.0%
Footwall Trap	A	33.8	20	155	0.13	4.74	0.93	1.95	36.3	7.4%	34.3	1.6%
	B	62.2	40	155	0.26	4.74	0.85	1.95	66.2	6.6%	63.1	1.5%
	C	85.4	60	155	0.39	4.74	0.77	1.95	89.8	5.1%	86.7	1.5%
	D	103.7	80	155	0.52	4.74	0.69	1.95	108.3	4.4%	105.2	1.5%
	E	116.7	100	155	0.65	4.74	0.62	1.95	121.7	4.3%	118.3	1.4%
	F	123.0	120	155	0.77	4.74	0.56	1.95	131.2	6.7%	125.3	1.9%
	G	125.3	140	155	0.90	4.74	0.49	1.95	134.0	6.9%	128.0	2.2%
	H	125.7	160	155	>1	4.74	0.45	1.95	135.0	7.4%	128.7	2.3%

Conclusions

With the continued increase in computer processing power, it has become common place for E&P professionals to use more sophisticated models to calculate GRV for the estimation of in-place hydrocarbons. Whilst these methods are a true advancement and offer the greater precision and breadth of applicability, it is perhaps useful to know that long-standing methods, can yield very similar results in a much shorter timeframe without the requirement of specialist software, and can provide essential QC of these sometimes complex models. It can even be argued that true understanding of the structural geometries of your trap is an essential tool in the box of an evaluator, and that technological advancements have resulted in a deterioration of these skillsets.

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