Composite sampling I: the Fundamental Sampling Principle

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From the first five columns, the avid reader will have acquired a good understanding of the difficulties of sampling, especially how heterogeneity interacts with the sampling process, producing all manner of detrimental effects, due to a series of identifiable sampling errors. We have presented a plethora of examples of heterogeneous lots and their varied manifestations—and stressed the resulting difficulties. Now is the time to start addressing the very reasonable question: what can be done about all this heterogeneity? Luckily there are many actions available, all stemming from the Theory of Sampling (TOS). Here we introduce the powerful concept of composite sampling in close relation with the Fundamental Sampling Principle (FSP). These are in fact the only two options available at the primary sampling stage, i.e. when facing the original sampling target and are therefore of paramount importance for all sampling, at all scales, for all materials…

WHAT TO DO with all this heterogeneity?

Trying to sample a(ny) heterogeneous lot with a single sampling operation, generically termed ***grab sampling***, is completely out of the question, for the simple reason that such a single sample (***"specimen***" rather) will never be able to ***represent*** a heterogeneous material (lot) in splendid isolation by itself, except in the rarest of accidental situations (and one would never be able to know when this was the case). This is regardless of whether the heterogeneity is visible or not. This latter point is worth emphasising because of the frequent situation of apparently visible uniformity, see Figure 1.

But there is hope—indeed a solution is immediately available. While in Figure 2 each individual grab sample (white circles) will fail for this reason—there is much more chance for an ***ensemble*** of such: a composite sample is defined as an ensemble of individual ***increments***, carefully spread out so as to cover the full geometry of the lot with the express intention to be accumulated into one aggregate sample, a composite sample.

The notion of a ***composite sample***, subject to a few, logical demands, will be shown to be the saviour of all sampling problems and issues that otherwise would have been left unsolvable. ***Composite sampling*** constitutes one of 10 sampling unit operations (SUO) with which to address all sampling problems (see later columns).

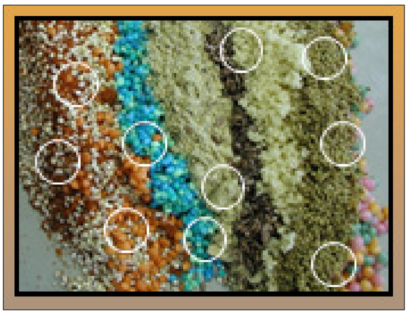

Figure 2. A set of individual grab samples (Q increments) destined to be aggregated goes a long way towards "covering" the lot in question, but certain further demands must also be met. It is not only about the magnitude of Q, i.e. it is not only about how many increments are used, but it is just as much about how these are deployed geometrically, i.e. are they covering the entire lot volume or not. This illustration is also pertinent to the issue of identifying a number of sampling errors, in this case fundamental sampling error (FSE) and grouping and segmentation error (GSE), of which more in later columns.

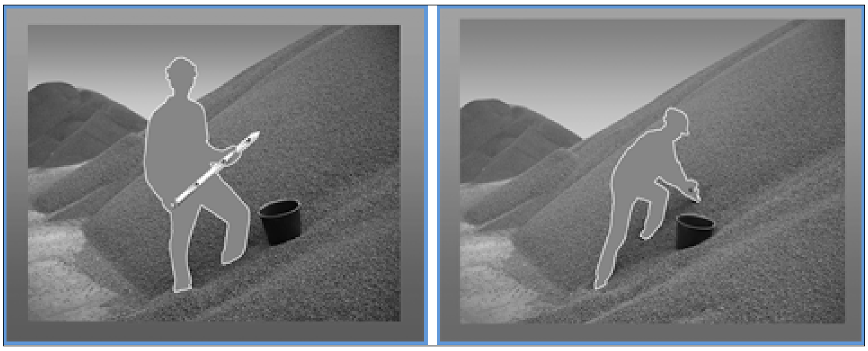

Figure 1. A single grab sample (specimen) is never able to represent the entire lot because it is manifestly not able to cover any material with a significant heterogeneity (compositional heterogeneity and distributional heterogeneity). This important truth holds for lots of ***all*** sizes, shapes and forms.

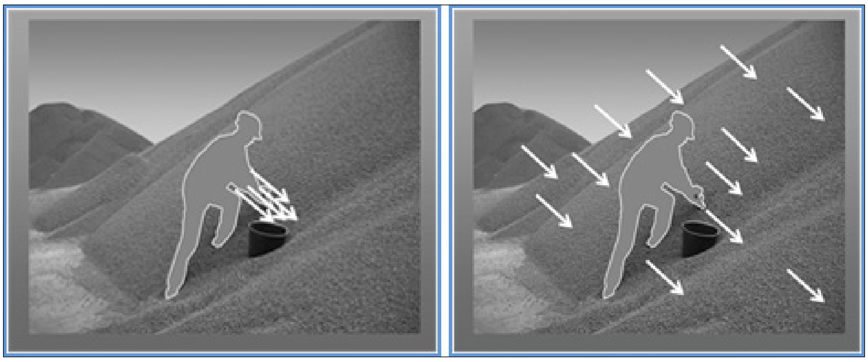

Figure 3. Local vs broad deployment of the same number of increments, *Q*. Note, however, that while the broadened-out deployment plan in the right panel does a much better job of "covering" the surface of the lot, it does not sample from within the significantly larger inner volume? How to "cover" a full-fledged 3-D lot?

For composite samples, the number of increments (*Q*) is of course important but ***only*** if deployed in a problem-dependent fashion, indeed only if covering the lot geometry adequately. Also rather paradoxically, if you think of traditional statistics, it is not ***only*** about the number of samples/increments, but it just as much about ***how*** these *Q* increments are deployed within the whole lot volume. For the situation depicted in Figure 2, a reasonable sampling coverage is beginning to see the light as *Q* increases… This is a situation easily depicted for a 2-D lot.

However, the situation becomes significantly more complex regarding stationary 3-D lots (e.g. piles, silos, vessels etc.). With respect to Figure 3, it is obviously not a solution to deploy *Q* increments only within a local, narrow footprint—this is getting exactly nowhere near even trying to "cover" the entire lot, see Figure 3 (left panel). What is needed is a broadening out of the sampling plan, but not only along the lot surface—it is imperative that the coverage is also able to sample the interior of the lot (pile in the case depicted).

Enter the **Fundamental Sampling Principle (FSP)**: all virtual increments in any lot must be susceptible to sampling and must have the same, non-zero probability of ending up in the final sample… All ***potential*** increments that might be identified in a composite sampling plan ***must*** be amendable to practical uncompromised extraction, no exception.

This means that even the sampling taking place in the right panel in Figure 3, cannot be said to uphold the FSP!

Composite sampling is good, but in itself not a panacea; it must comply with the demands of the FSP as well. Composite sampling is a ***necessary*** condition, but it only becomes ***sufficient*** when also obeying the FSP. FSP constitutes another of the 10 SUOs. These two ***governing principles*** apply to lots of all dimensionalities, 0-D,† 1-D, 2-D as well as 3-D lots.

Figures 4–7 show a remarkable difference in appearance, yet they all illustrate the necessary compliance between composite sampling and the FSP.

1-D lots are not really 1-D lots like a geometric line, but lots in which one of the dimensions completely dominates the two others, Figure 6. While being 3-D lots in principle, because of TOS' demands that any increment extracted

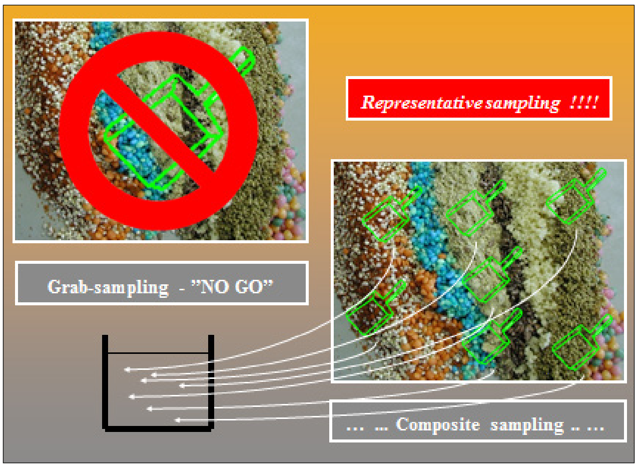

Figure 4. Composite sampling ($Q = 7$) does a much better job than a single grab sample of the same mass/size. FSP-compliant composite sampling is the only way towards representative sampling, and is in fact only dependent upon the magnitude of *Q*—the more (smaller) increments the better.

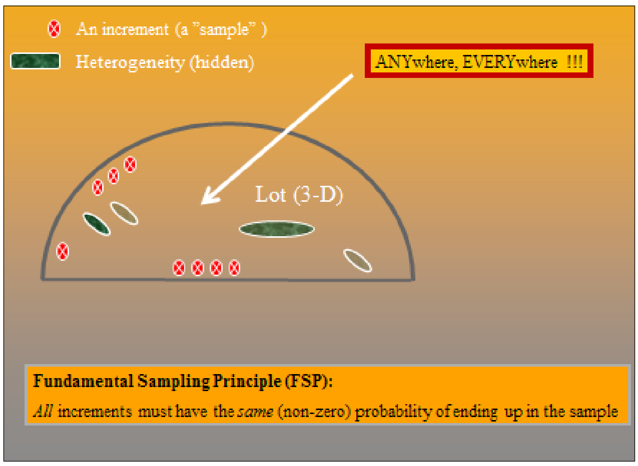

Figure 5. The FSP demands that all potential increments must have the same, non-zero probability of being extracted. It is emphatically not enough to broaden out a sampling plan only along the surface of a 3-D lot. The inner volume (by far the largest volume fraction of any 3-D body) must be amenable to sampling with respect to the full lot volume.

†The special case of a zero-dimensional lot refers to a lot that can be effectively, mixed, moved and sampled throughout with complete sampling correctness (to be explained). Usually these are "small lots", which can easily be manipulated.

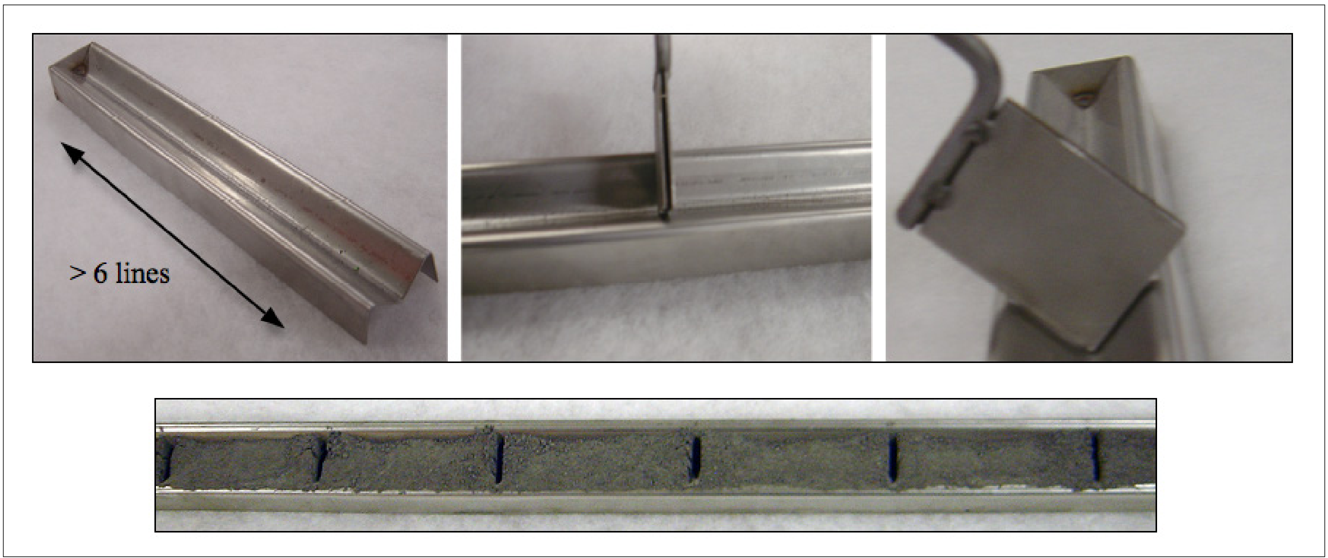

Figure 6. Bed-blending technique applying both composite sampling and FSP. The primary sample material is first laid out in a multiple layer stacking operation, in this case in six layers (called "lines"). In the literature this technique is commonly referred to as ***bed-blending***, a particularly efficient form of pre-mixing. Note how the thin extraction device covers the full width and depth of the material and thus covers the two transverse dimensions completely. The lower panel shows six out of a total of seven transverse thin-slice extractions.

from such a lot must cover the two other dimensions completely, this lot becomes a true 1-D in practice: it is only the heterogeneity in the dominating elongated dimension that matters since all "transverse heterogeneity" has been successfully represented in each increment.

Figure 6 shows a powder manifestation of a 1-D lot (the lot material is power plant incineration ash which needs characterisation and hence primary samples are collected from the incinerator), but in fact Figure 6 illustrates the procedure used in the laboratory for sub-sampling the primary samples. Here compliance with the FSP is secured through application of the operation of "bed-blending". ***All*** of the primary sample material is laid out in the sampling rack—in this particular case in six layers, but preferentially as many as possible, after which the sampling procedure enjoys complete access to "everywhere" in the lot.

In this example, 7 transverse increments were extracted, but this in reality corresponds to no less than 42 increments in total, since the material was laid out in 6 beds originally, i.e. 6 beds × 7 increments. This compound composite sampling approach is called: "bed-blending stacking/thin-slice reclaiming". It can be very effective when it is acknowledged that the total number of increments scales with the number of beds laid down (*B*) times the number of full

Figure 7. Even with "difficult materials" (coarser grains, "clumpy constitution"), bed-blending/thin-slice reclaiming is still often possible. Here is shown a particularly inexpensive laboratory sampling procedure improvement case, essentially with no costs. A willingness to invest just a little work to understand the principles of TOS is all that counts. N.B. the sampling procedure developed in this example ended up using many more increments than the two shown here… in fact the company involved developed several versions (each with its own specific *Q* that targeted to a "typical" heterogeneity representative of 13 principal types of materials dealt with).

transverse cuts extracted (*Q*). It is worth noting that each thin-slice increment is in effect a small *B*-composite sample in its own right, made up of *B* constituting layer-increments. These $B \times Q$ increments are demonstrably covering the entire geometric volume of the precursor lot irrespective of its form, geometry and mass—because one has made the effort of stringing the complete lot material out in a 1-D linear manifestation (albeit folded), making compliance with FSP both easy and very effective. The combined operation is a kind of ***lot dimensionality transformation (LDT)***, from 3-D to 1-D. LDT is another of the 10 SUOs, more of which later.

Note that this technique can be applied to any scale and is in fact often used for primary lot sampling and blending/mixing purposes of bulk material occurring in significant tonnages.

By extracting several increments at regular intervals along the elongated dimension (or at random positions), a particularly effective sampling is achieved by aggregating all increments. By this approach the entire lot volume (the entire primary sample volume) is ***guaranteed*** to be available for sampling and this composite sampling process therefore complies entirely with the FSP. This is of interest also for coarser fragment aggregates, which traditionally are considered as "difficult" to sample.

Figure 7 shows such a case also subjected to "bed-blending/thin-slice reclaiming" in an impromptu implementation. Note that this technique is not necessarily associated with a particular type, or brand, of equipment—on the contrary: until this type of laboratory sampling was demonstrated (for a world-class company with a strong laboratory tradition) simple spatula-based grab sampling had been ruling for years/decades… "because there is no other equipment available" (*sic.*).

Which materials, which company, which laboratory… is of absolutely no interest—the only thing that matters is that a simple, essentially no-cost solution [a piece of cardboard (folded) and a high-walled spatula] was able to transform the world's worst sampling procedure (grab sampling) to an unsurpassed, representative procedure (bed-blending/thin-slice reclaiming) because of understanding and respect for TOS in general, and for the FSP in particular. Figure 7 is a role model sampling procedure improvement example.

There are many other variations on the theme of composite sampling + FSP in the world of science, technology and industry, but the present introduction should allow easy recognition. The next column will show more examples of the versatility and effectiveness of composite sampling especially for sampling dynamic lots, i.e. moving streams of matter (process sampling).