

Seismic Facies Mapping-Getting More Geology into Your Play.

Rob Kirk*

Consultant

PO Box 133,

Nubeena, Tasmania, 7184.

robkirkconsultants@bigpond.com

SUMMARY

Seismic facies mapping is an underutilized tool for getting extra geology in to your exploration, or development. It is a key component of palaeogeography mapping that help show different types and locations of seals and reservoirs.

Both manual and automated facies mapping, on 2D and 3D seismic, when calibrated to local wells, can help de-risk crucial components of a play.

In many areas today where deep water or new frontier exploration is undertaken, there is often little or no well control and seismic facies mapping, allied to analogues, may be your only tool for getting at the geology in your palaeogeography maps.

This talk will apply geological models to, and discuss, the construction of manual seismic facies maps which are then used to guide automated facies map work.

Manual facies mapping is undertaken once sequence boundaries have been mapped and named. Each different facies identified is given the name of upper and lower boundaries and the facies name and then the horizon is picked so that the facies extent is shown on a base map. Once completed, polygons encompass this facies. The final map uses all polygons constructed, along with well logs for that sequence.

Automated facies maps start with RMS and maximum amplitude maps of the sequence, then possibly of proportional slices within the sequence and then we may construct waveform facies maps or spectral decomposition maps of the interval.

All these maps are considered with the interval's isochron map and at least gamma log windows at wells, with appropriate geology transcribed to finally construct the palaeogeography map of the interval.

Key words: seismic facies, palaeogeography.

INTRODUCTION

A quick perusal of the current literature shows few papers on manual seismic facies mapping being used for palaeogeography map construction. There are a useful handful of papers constructing automated facies maps on 3D seismic data but, nevertheless, these are not always base line products routinely produced by companies. The reader is referred to a selection of interesting papers in the reference section.

This paper is to encourage explorers to use such methodology to get that extra geology from their data. The maps can show where the different reservoir types are located and their traps, as well as the seals, and even source rock quality, under the right circumstances.

The methodology alone gets the explorer looking thoroughly at all aspects of the data-from the well composite logs and accessories, to big cores, to the detailed seismic facies variations in each of, usually, at least a dozen distinct seismic intervals.

The picking methodology can be different to that of the structural picker as the continual use of geological models leads the picker to regularly try alternate model picks.

Most seismic interpretation software today still does not allow one to easily pick geometries, or amplitude and continuity swathes on the data, especially within a horizon framework. It is partially our own fault as the large companies which developers listen to have asked the software people to concentrate on structure and not on stratigraphy-at least for 2D work and manual work on 3D data sets. Nevertheless we can "invent" different ways of manually constructing maps.

A normal work flow is to work the data structurally (at a certain scale) and then start the stratigraphic seismic work (at varying scales and aspect ratios). The difficult part is to break out the intervals that will be studied. Once this is done manual maps are attempted for each interval, and then automated maps are made (if on 3D). In parallel to this (or beforehand) the well data are worked up, ready to be incorporated in to the seismic work. Both seismic and well data need to be "fitted" to an appropriate geological model. Finally, palaeogeographic maps are made for each interval. This should be a truly integrated process-Figure 1.

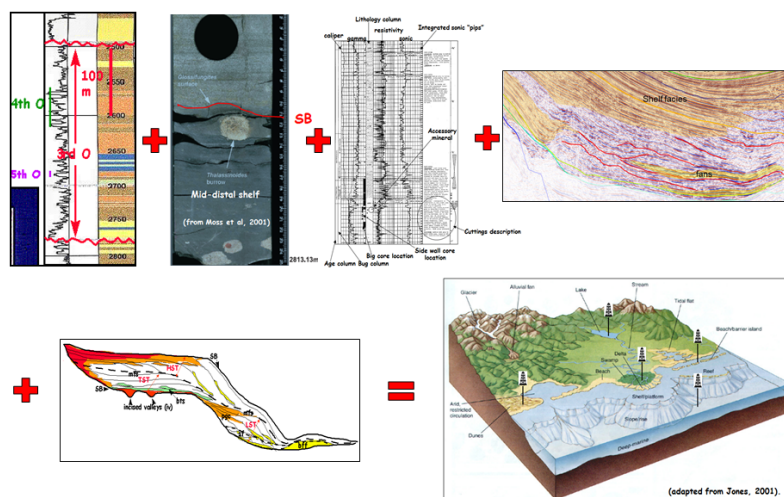


Figure 1. The final palaeogeography map can have input from well logs, cores, and seismic, all fitted to a geological model.

METHOD AND RESULTS

The sequence stratigraphic work usually commences with getting all the well data together. These are crucial in calibrating the different seismic facies belts that we map. Collect all logs, composite and mud logs and core data and organize them sensibly. It is useful to set the wells up in a series of Well Sections—dip and strike lines of wells across the study area. Usually gamma and sonic logs with a lithology column will suffice, along with down hole bio zone data.

The well data are put in to an initial sequence framework using a standard geological model such as the 3 system tract model of Peter Vail and Walt Wornardt (1991), or the 4 system tract model of Zechin and Catuneanu (2012), or even the 2 system tract model of Embry (2002).

Figure 2 shows the Vail model with seismic facies from Alaska, Carnarvon Basin, Gulf of Mexico, Great Australian Bight, Malay Basin and Morocco.

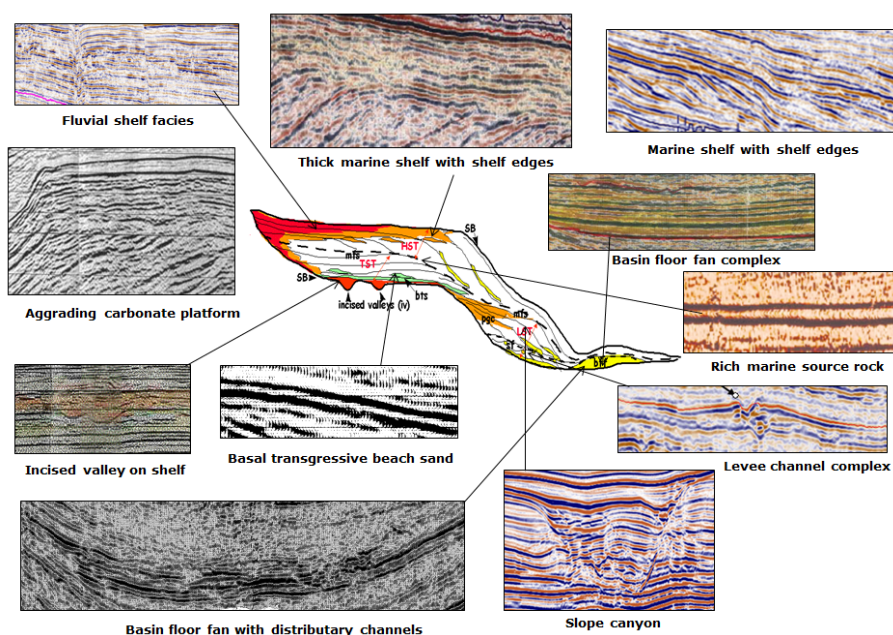


Figure 2. Geological model with different seismic facies “calibrating” it.

We usually make quick palaeogeography maps using very basic data, before the seismic picking. Using your best isochron or isopach map of the study interval post the gamma log windows of this interval from all wells—these need to have marine, non-marine data as well as any other environmental data that is relevant. Then manually contour the different facies belts (such as beach sand, deltas, fluvial and fans) using the logs. These maps will be updated once the much more time consuming seismic facies belts have been determined.

When you start on the seismic grid (which has already been mistie-corrected, balanced, good time-depth curves applied etc.) go through all the data and look for the “Rosetta Stone” line—there is always a key line to show what you are looking for. Use this line to

design appropriate scales and, especially, aspect ratios, to work the different intervals on. Your eye will become attuned to roughly the number of cycles in the data set. Slowly changing facies can be worked at one scale and aspect ratio while quickly changing facies need different ones. Use colour on the seismic, not just black and white. The extra colour allows you to see more subtle stratigraphy.

Start the 3D picking work at a coarse interval, often every 100 (or 250) inline, cross line. Be careful with horizon naming conventions. I prefer to number from old to young, often with an age identifier in the name. I never use millions of years, or maximum flooding surface, transgressive surface etc.-as these usually change by the end of a job-unless you have a lot of worked data already in the area. If this is a new frontier area for your company and you have little data you can just start with Reg_100, Reg_200 or similar (“Reg”=regional). You always end up adding new horizons so with a scheme like this it is easy to add Reg_150 etc. You can rename them later when you better understand the area.

You need to work the faults and structure as you go but keep them as thin lines so you can see the stratigraphy through them.

You will soon get a feel for the 2nd order coarse packaging-usually related to basin-forming tectonics. We want to get down to the 3rd order (“sequence”) packaging for facies mapping if we can.

The manual facies entails mapping geometries (channels, mounds, onlaps, downlaps, prograding and truncation) which is easy on hard copy with a red pencil but not so easy on the machine-can use faults if you want.

After geometries we need to map the different amplitude and continuity belts. In the workshop setting at the beginning of many jobs the team uses a hard copy grid and pencil colours are allocated to different facies such as high amplitude and continuity (“HAC”) shelf or basin facies, low amplitude and low continuity shelf or basin facies (“LAC”).

Figure 3 shows a manual seismic facies map from the Malay Basin (Wong, 2006) and a sophisticated waveform automated seismic facies map from Gabon.

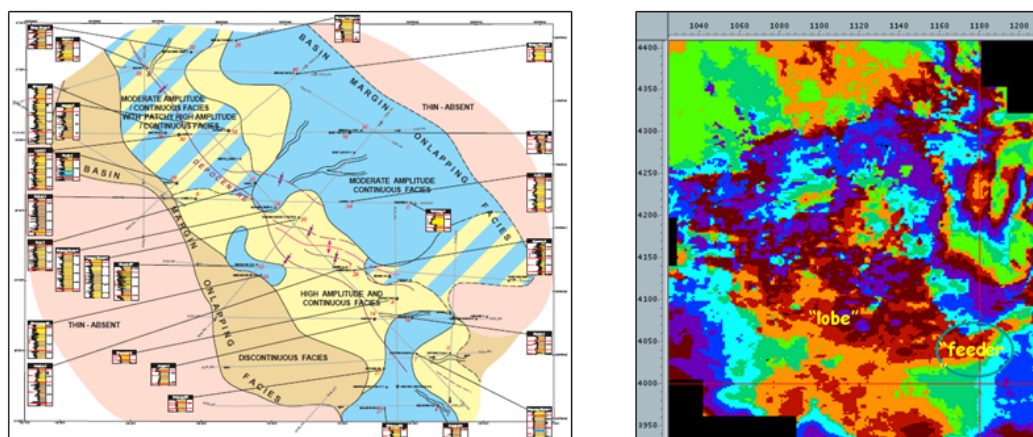


Figure 3. Manual seismic facies map (left) and waveform automated seismic facies map (right).

How to do this once back on the machine? It would be nice if developers gave us tools where we could mark on belts of amplitude-continuity, as well as the different geometries quickly (using the mouse and hot buttons maybe?) and have these associated with a particular pair of horizons that bound the mapped interval. They would then be displayed on the base map and we could use named polygons for these facies.

Some companies used to use the A-B/C method to map geometries only (Kirk, 1985). Others used three letters to describe the facies and hard-wired this to a colour pallet, so hot pink=HCM (H=high amplitude, C=continuous, M=mounded). Shell (Prather et al, 1998) in the deep water Gulf of Mexico use letters for digital manual mapping. For example, Cbh=convergent baselap, high amplitude, Ctl=convergent, thinning, low amplitude facies, D=high amplitude draping events, Bl=low amplitude chaotic data.

The following method works well and has the benefit that the horizons can be sent to partners and they can look at your facies on their project and adjudicate on them. You do not want to have this as an unknown “black box” process that only you can understand-it is unlikely to be accepted.

The hard work is getting the 3rd order horizons finalized. By this stage you will have integrated the seismic with the well logs and updated the Well Sections. You have been using the gamma logs on the seismic with well composite logs easily at hand for the entire seismic work. If you do not have a thorough knowledge of your wells then obtain it before continuing!

Let us say that we have a basal horizon-Reg_100 and an upper horizon Reg_200. Turn all other horizons off and turn any faults off that were not syndepositionally active during deposition of the 100_200 sequence. We only want active faults on our facies and palaeogeography maps (all others are post-deposition).

Quickly work this sequence on many lines for the likely range of mappable facies that you see. Each facies will be a different horizon.

For example if we have a basal high amplitude mound we will name that facies as Reg100_Reg200_basal_hiamp_mound, other facies may be Reg100_Reg200_mid-cycle_channels, Reg100_Reg200_upperHAC sheets etc. The “template” we are using is obviously: basal horizon_upper horizon_facies name.

Figures 4 through 6 show this visually).

When we are mapping, say, the basal mound, turn that facies horizon on and go through each line and, where you see the facies, pick it from one end to the other, preferably above or below the sequence boundaries and not within the sequence. All we are after is the range of this facies on each line and to be able to see that on the map. When finished, simply draw polygons around the facies and name them with the facies name, so you might have Reg100_Reg_200_basalHACmound1, ditto 2, ditto 3 polygons.

Repeat this for all facies and then turn on all the different facies polygons. It is useful to colour/pattern code these, for example, mounds=yellow, channels=red, HAC sheets=blue etc. Add these polygons to the simple well log palaeogeography maps that you have already made and start re-drawing using these new facies belts.

You may have to do some of the calibrated well log windows via drafting packages (ArcGIS would be useful here) but some software (like Petrel) can take the sequence boundary (“tops”) spreadsheet and cut out, and post, the appropriate gamma log window on to a map.

This work often needs some group discussions on how to proceed (and these are also useful for distributing “blame” for after the well!).

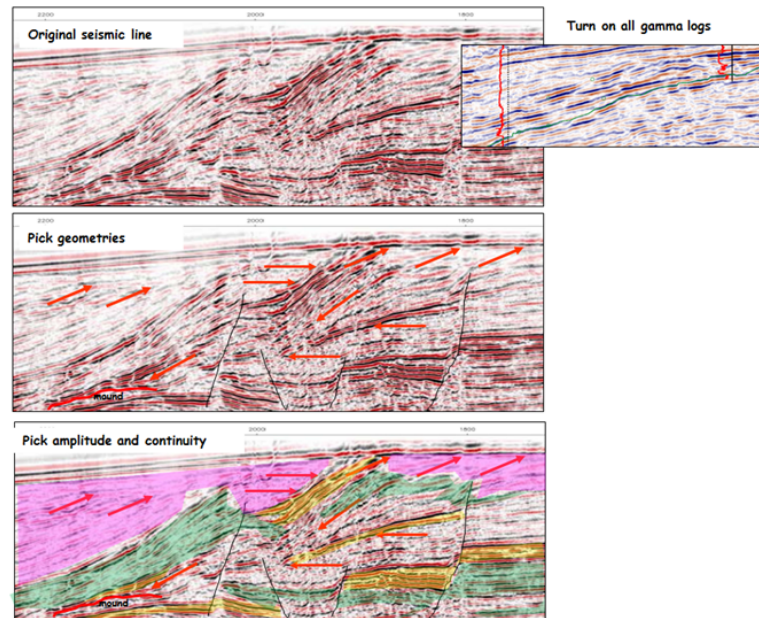


Figure 4. Manual seismic facies mapping procedure.

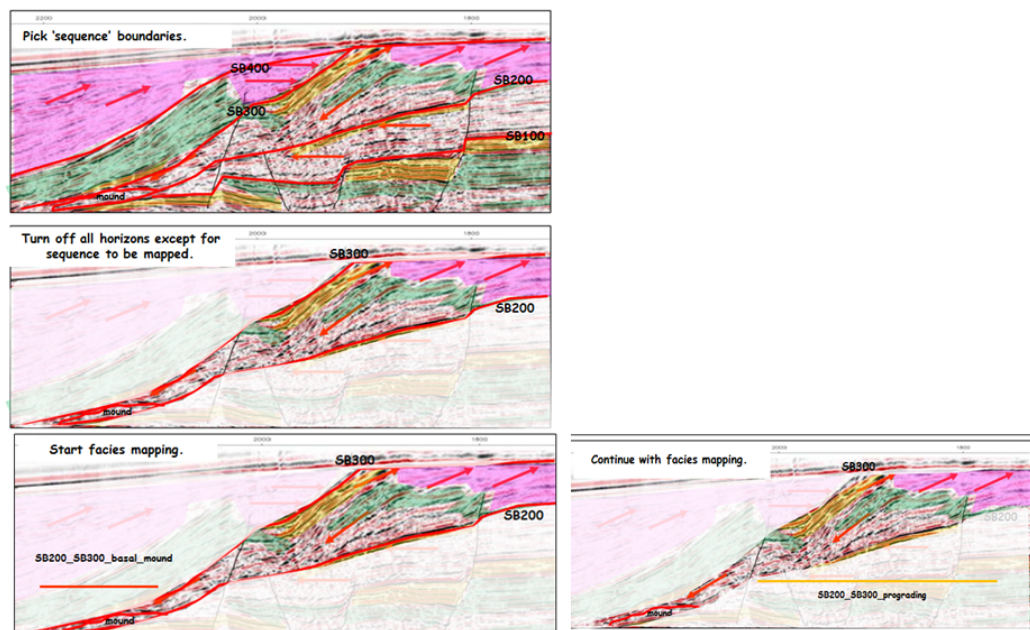


Figure 5. Manual seismic facies mapping procedure-continued.

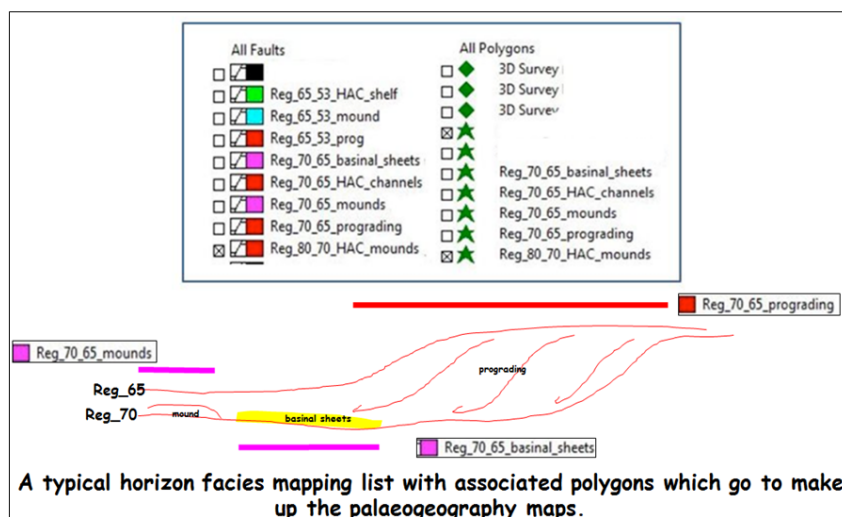


Figure 6. Manual seismic facies mapping procedure-continued.

Once the manual work is completed you usually have a good understanding of how to proceed with the automated facies work.

Normally I find a 100IL by 100XL (or 50IL by 50XL) picked grid is satisfactory for the first round of automated work-so grid the horizons and make isochrons.

Usually I will get the RMS amplitude of the sequence along with maximum/minimum amplitude. Then it can be useful to construct proportional slices and extract amplitudes on them and between them. If your software does not have a “proportional slice button” just use the isochron (I) to make the new horizon slices. Take the upper horizon (H) and add on, say, I/5, for 5 intervals. The first slice is therefore $H+I/5$, 2nd slice is $H+2I/5$ and the final slice is the basal horizon already picked ($=H+5I/5$).

Lately I have been intrigued with the results of spectral decomposition (see Zeng, 2013) where the data are broken up in to a few different frequency bands, and assigned different colours to each band. It appears that different stratigraphy tunes at different, and tight, frequencies. This looks most interesting and I would like to try it on source rocks, for example, as I find that these are very susceptible to tuning at low frequencies-even to the point of adding 3 or 4 Hertz at the bottom end of the wavelet.

After these “basic” automated facies maps try something more sophisticated, such as waveform facies mapping (Stratimagic and Seisnetics). I have had amazing facies come out of such software-that left previous standard work way behind.

I have also used Principle Components (“PC”) on one job and it really appeared that the software was “filtering” the different facies from the Miocene fluvial environment that I was working in. PC1 had the large crevasse splays and channels and PC3, 4 had smaller ones. Many of these later PC’s were not seen on the standard amplitude maps.

Sometimes you may not get much out of the manual facies mapping, just as sometimes you get little from the 3D and more from the manual.

Always attempt both facies mapping procedures as they usually complement each other-as found when mapping in the Rankin trend Triassic reservoirs (Seggie et al, 2007).

Figure 7 shows some manual seismic facies maps from over 30 years ago that were part of the work that led to the discovery of the Harriet group of fields. The left map shows the shallow shelf of the Zeepaard sequence with a large incised valley in it. The second map shows “elongated, HAC mounds down dip from the valley-the latter having supplied sands to the basin floor. Over 20 exploration wells were drilled in this permit and all had seismic facies mapping as a standard product.

Figure 8 shows some automated seismic facies maps from South East Asia, Miocene. The black and white maps are RMS amplitudes of the interval while the coloured maps are waveform facies of the same interval. You can see that the maps show different things so they are both useful to have.

Figure 9 shows waveforms automatically generated for the entire 3D cube in processing. Just clicking anywhere in the cube brings up amplitude and different forms of waveform facies maps. The upper section is a 3D view rotated to look beneath the waveform map so we can see the Neocomian prograding slopes.

The view is tilted back down in the lower picture and we are looking at the facies of the shelf, shelf edge and slope. Note the narrow erosional gullies running down the slope.

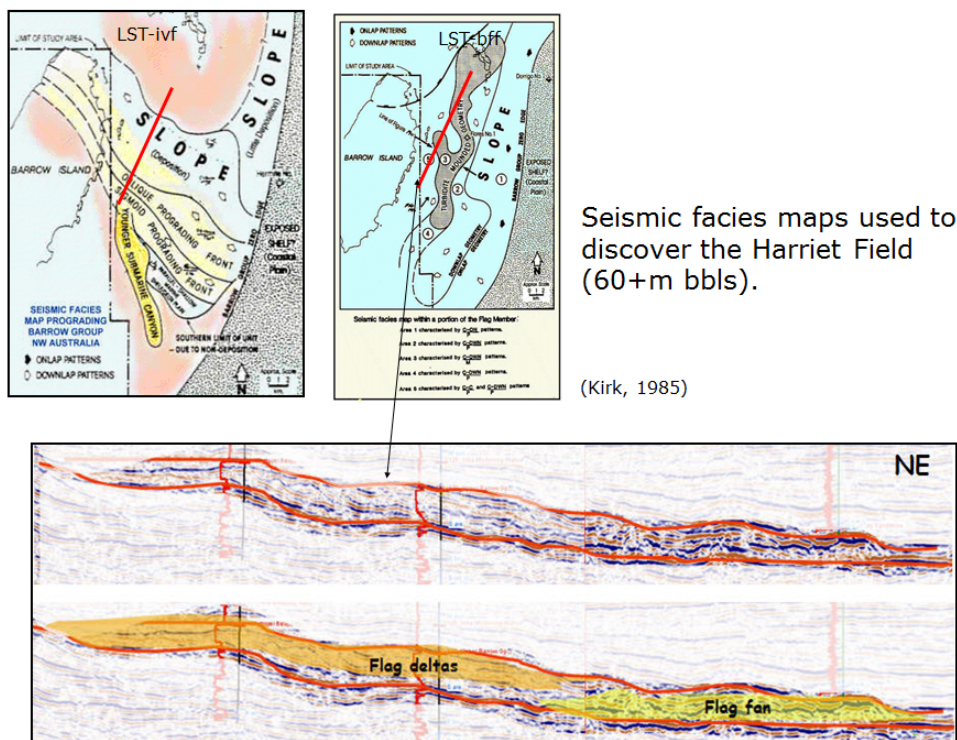


Figure 7. Manual seismic facies mapping used to find the Harriet Field, Barrow Sub-basin..

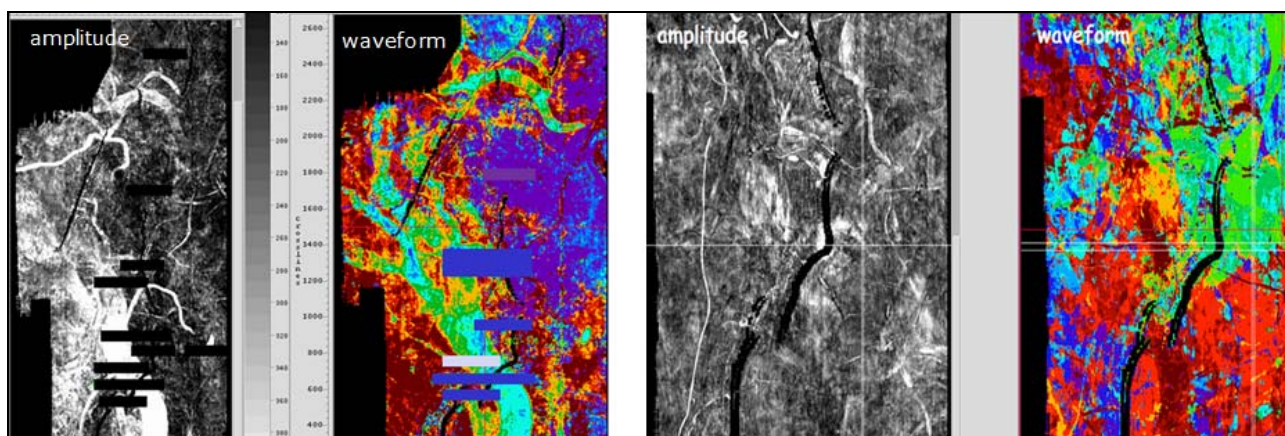


Figure 8. Automated seismic facies maps-amplitude and waveform, SE Asia.

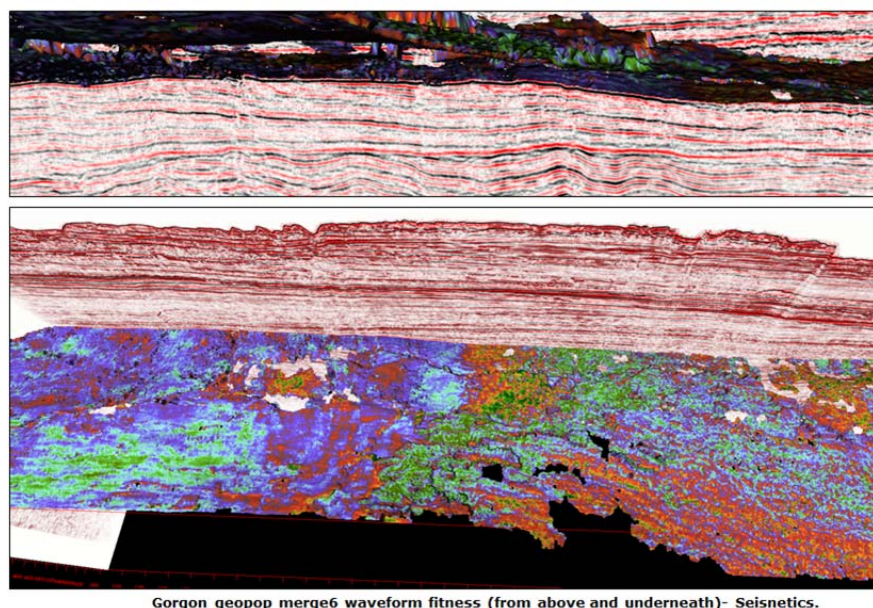


Figure 9. Automatically generated seismic facies waveform map-Barrow Group- prograding from beneath (upper) to see the prograding unit, and above (below) to see the facies variations on the shelf and the slope (courtesy Total Depth Pty. Ltd.).

CONCLUSIONS

Very few companies have active manual seismic facies mapping geoscientists. This statement is from consulting work but also from “mining” of the AAPG Bulletin. Only a handful of papers involved manual facies mapping, while many had automated maps which were of the “unsophisticated” type, and not waveforms, neural networking, spectral decomposition etc.

Manual facies mapping is easy and quick to do (the hard part is getting the sequence boundaries picked) and usually offers something useful to the exploration work. For example, one of the most common patterns on a shelf is that of LAC facies landward, interfingering seaward with HAC facies-not readily seen on 3D data (this is better at looking at rapid amplitude changes rather than slowly varying ones). These are the inboard fluvial belts undergoing marine influence in to the deltaic belts. Such facies changes are seen in the Triassic of the Barrow and the Jurassic of the Dampier Basins, the Cretaceous of the Great Australian Bight Basin and the Tertiary of most of SE Asia. In the latter there is often a manual HAC facies belt of higher amplitudes outboard of the deltas-being a narrow carbonate platform that interfingers with the deltas.

In Alaska we were able to map manually source rock differences in the Cretaceous Pebble Shale.

Basin floor fans usually have some form of difference from basin to basin and invariably the manual facies maps help determine what it is. This manual work is then used to “ask sensible questions of” the 3D data, via automated mapping.

Many companies have some form of automated seismic facies mapping input to their exploration and development but often it is not treated as a key item and may not be run under “geological auspices”. Often when these are scrutinized it is apparent that little “ground truthing” of the “geology” on them has been done-often noise or structure is incorporated. Often stratigraphy still remains “hidden” in these maps because further detailed work had not been undertaken, possibly due to a detailed lack of knowledge of the local geology. The RMS amplitude map of a sequence is the first automated map made but can be misleading as it “averages” the data over the interval, just as the maximum or minimum amplitude map can show elements from both the base or the top of the sequence “jumbled together”.

These automated maps are vital tools for getting at the geology but they are usually left at the initial “unsophisticated” stage. Go the extra mile and look at waveforms, for example. In one job in Miocene fluvial sediments we had several wells-some were in meandering channels with sand and oil, some sand and brine and some mud filled. We were able to define 7 key wells that drilled the spread of outcomes-sand versus mud, brine versus oil in the stratigraphic trap channels. We extracted the wavelet over the key interval in each of these wells and then asked the software to rebuild the entire 3D data set of the interval using those 7 wavelets and show how well the real data fitted these wavelets. The resulting facies map appeared to show the mud filled channels, the brine filled sand channels and maybe even the oil filled sand channels.

In conclusion, give manual seismic facies mapping a try in your exploration or development area. Ally this to the automated mapping -meaning, do not have different people run them-maybe use a team that works together. This work needs to be done by geoscientists thinking geology all the time. They are confident enough to look over the sedimentologist’s shoulder at the core shed, to discuss environmental bio zones with the biostratigrapher, as well as amplitude balancing issues with the processing geophysicist. They need to be regularly sent on field trips (and made to “sing for their supper” when they return!) so they do not lose contact with hard geology as opposed to the soft geology we normally use (logs and seismic).

REFERENCES

- Bourget, J., Nanson, R., Ainsworth, B., Courgeon, S., Jorry, S. and Al-anzi, H., (2013), Seismic stratigraphy of a Pliocene-Quaternary intra-shelf basin, Bonaparte Shelf, NW Australia, in West Australian Basins Symposium Proceedings.
- Burton, D., and Wood, L., (2010), Seismic geomorphology and tectonostratigraphic fill of half grabens, West Natuna Basin, Indonesia, AAPG Bulletin, 94, 11, pp 1695-1712.
- Dirstein, J., Rudge, T., and Stanley, A., (2013), Insights from the automated extraction of surfaces from the Bunda 3D seismic survey, in West Australian Basins Symposium Proceedings.
- Embry, A., (2002), Transgressive-regressive sequence stratigraphy, 22nd Annual GCSSEPM Foundation Research Conference.
- Escalona, A. and Yang, W., (2013), Subsidence controls on foreland basin development of NW offshore Cuba, SE Gulf of Mexico, AAPG Bulletin, Vol. 97, No. 1, pp. 1-25.
- Gong, C., (2015), Shelf edge trajectories and stratal stacking patterns: their sequence stratigraphic significance and relation to styles of deep water sedimentation and amount of deep water sandstone, AAPG Bulletin, Vol. 99, No. 7, pp. 1211-1243.
- Jiang, S. et al, (2013), Sequence stratigraphic architecture and sand body distribution in Cainozoic rifted lacustrine basins, east China, AAPG Bulletin, Vol. 97, No. 9, pp. 1447-1475.
- Kirk, R.B. (1985) A seismic stratigraphic case history in the Eastern Barrow Sub-basin, Northwest Shelf, Australia. AAPG Memoir No. 39, pp. 183-208.
- Liu, J., et al, (2013), Volcanic rock-hosted natural hydrocarbon resources a review, Intech open access article, <http://dx.doi.org/10.5772/54587>
- Mee, B. (2001), Seismic sequence stratigraphy of the late Cretaceous Ceduna Sub-basin, Great Australian Bight, BSc (Hons) thesis, NCPGG, University of Adelaide.
- O'Halloran, G., Hurren, C. and O'Hara, T, (2013), Seismic stratigraphic relationships within a low stand reservoir system: examples from the Barrow group, southern Exmouth Sub-basin, NW Australia, in West Australian Basins Symposium Proceedings.
- Poynter, S., Goldberg, A. and Hearty, D (2013), Sedimentary and structural features of the Pliocene-Pleistocene Timor accretionary wedge, Timor-Leste, in West Australian Basins Symposium Proceedings.
- Prather, B., Booth, J., Steffens, G., Craig, P., (1998), Classification, lithologic calibration, and stratigraphic succession of seismic facies of intraslope basins, deep water GOM, AAPG Bulletin, Vol. 82, No. 5.
- Seggie, R., Lang, S., Marshall, N., Cubitt, C., Alsop, D., Kirk, R., Twartz, S., (2007), Integrated multi-disciplinary analysis of the Rankin Trend gas reservoirs North West Shelf, Australia, APPEA Journal.
- Takano, O., Itoh, Y. and Kusumoto, S., (2013), Variation in fore arc basin configuration and basin-filling depositional systems-fore arc basins, Japan, in Mechanism of Sedimentary Basin Formation, Multidisciplinary Approach to Active Plate Margins, Intech open access article, <http://dx.doi.org/10.5772/56751>
- Vail, P. & Wornardt, W. (1991) Well, Seismic and Log Sequence Stratigraphy. AAPG Course, Dallas, April.
- Wong, R., (2006), A regional sequence stratigraphic study of the Malay Basin, Malaysia, AAPG International Conference, Perth, Western Australia.
- Zecchin, M. & Catuneanu, O., (2012), High resolution sequence stratigraphy of clastic shelves I: units and bounding surfaces, Marine and Petroleum Geology No. 39, pp. 1-25.
- Zeng, H., (2013), Frequency-dependent seismic-stratigraphic and facies interpretation, AAPG Bulletin, Vol. 97, No. 2, pp 201-221.
- Zeng, H., Hentz, T., (2004), High frequency sequence stratigraphy from seismic sedimentology: applied to Miocene, Vermilion Block 50, Tiger Shoal area, GOM, AAPG Bulletin, Vol. 88, No. 2, pp 153-174.