- ❍ What will happen on the seismic section as a sequence boundary is traced out laterally in a distal direction?
- ● The seismic reflector will become less well marked because the erosional truncation and change in lithology will gradually become less until the unconformity becomes a correlative conformity.

As a sequence boundary is traced from an unconformity in the proximal sections to a correlative conformity in distal sections, the type of reflector termination underlying the sequence boundary will change from erosional truncation to *toplap* (Figure 4.22). An analogue to this is a perfect set of cross-stratified beds dipping towards the right with the top and bottom of the beds curving to a shallower angle so that they run tangentially to the horizontal. If we now erode the top of the cross-stratified beds along an inclined surface dipping towards the left (Figure 4.23), we are left with erosional truncation on the left-hand side and toplap on the right-hand side. Sediments deposited on top of the erosional truncation surface will show an *onlap* geometry (Figure 4.22).

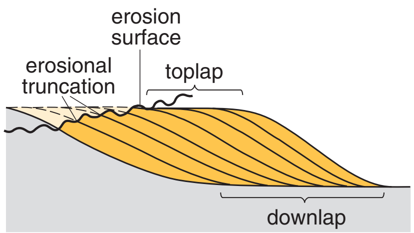

Figure 4.23 Cartoon showing the difference between erosional truncation and toplap.

Maximum flooding surfaces can often be picked out on seismic sections if the overlying HST is composed of clinoforms, the toes of which run tangentially into the maximum flooding surface; this kind of termination is called *downlap* (Figures 4.22 and 4.23).

Thus, the reflector termination characteristics of chronostratigraphical surfaces can be used to delineate key sequence stratigraphical surfaces and hence systems tracts and individual sequences. Most commonly, sequence boundaries are characterized by erosional truncation and toplap below the surface and onlap on top of the surface (Figure 4.22); transgressive surfaces are characterized by onlap; and maximum flooding surfaces are characterized by downlap of the overlying sediments onto the flooding surface (Figure 4.22). These features may also be recognizable within individual exposures, especially large-scale cliffs, and can also sometimes be deduced by compiling many sections.

Box 4.2 Seismic reflection surveying

Seismic reflection surveying is a geophysical technique used by the oil industry and research groups to derive subsurface geological information. It has been used particularly in the study of sedimentary basins, and can be done on land or at sea. Seismic waves are sound waves generated by a seismic source; they then travel through the subsurface, are reflected at geological boundaries within the subsurface and return to the surface where they are recorded. This is shown as wave 1 reflected from reflector 1 (Figure 4.24a). Wave 2 has been both reflected by reflector 2 and refracted (or bent) by reflector 1. Thus, a picture of the subsurface geology can be compiled. The record of ground motion (or pressure variation at sea) with time when plotted on paper is called a seismic trace (Figure 4.24b). The amplitude of a reflection is a measure of the strength of the ground motion, shown by the deviation of the seismic trace. Individual seismic traces are the result of a complex stacking of many seismic traces (the details of which we will not consider here), which act to reduce background noise (e.g., from nearby roads in land surveys or ships in marine surveys). A number of seismic traces displayed side by side form a seismic section (Figures 4.22b, 4.24c,d). This is a representation of a slice of the Earth and is produced by moving the source and detectors along the line of survey. Shots are fired at a regular horizontal distance apart (usually around 25 m). In order to make the reflections more easily visible, the right-hand half of the amplitude of the seismic wave trace is usually coloured black (compare Figure 4.24c with Figure 4.24d).

The horizontal scale of a seismic section is a measure of horizontal distance along the line of survey. The vertical scale is the two-way time of the seismic wave, i.e. the time taken for the wave to travel down into the ground and back up again after reflection.

When interpreting seismic sections, the section is examined for reflection continuity. Continuity is where a reflection on a trace can also be recognized on neighbouring traces, with only small changes in the arrival time. Because half of the seismic trace is coloured black, such continuities appear as black or white lines running across the section (Figure 4.22b: note that in this Figure, the black has been converted to grey so the interpretation can be seen). These continuities are termed reflectors and are generated by interfaces where the density and/or acoustic velocity (speed of sound in the material) of the rock and/or its fluid content changes. The product of the density and sonic velocity of a material is termed its *acoustic impedance*. The interfaces may be bedding planes but may also be fault planes or any other extensive boundary between rock types. In some areas, there may be few or no seismic reflectors because there are no reflecting interfaces; too deep for sufficient seismic energy to reach (seismic energy is attenuated as it travels through the Earth); or a very complex structure.

The fact that the vertical scale is measured in two-way time and not in depth is important because it means that a seismic section is *not* a true geological cross-section through the Earth.

- ❍ What extra information would we need to convert a seismic section into a geological cross-section?
- ● The velocity of each of the rock layers because $v = d/t$ where v = velocity, d = distance and t = time.

As this velocity will vary for each different lithology, this is no easy task. Oil companies need such information because they have to calculate how deep to drill in order to intersect an oil reservoir within a geological structure. Whilst it can be obtained by computer modelling, the only precise way to calculate velocities is to drill a borehole somewhere along the line of the seismic section and then to measure directly the time taken for a sound wave to pass through each of the rock units within the borehole. This gives the time it takes a seismic wave to reach any specified depth in the borehole. Where this depth corresponds to a major change in rock type capable of generating a seismic reflector, we can use this time to locate the corresponding reflector on the seismic section. This is called 'tying the well to the seismic section' and allows information obtained on the various rocks in the borehole to be extrapolated along the seismic section. The configuration, continuity, amplitude, frequency and interval velocity of seismic reflection patterns can be used to predict the lithological content of the subsurface packages (seismic facies analysis).

It should be realized that this is a very simplified explanation of how seismic sections can be used to derive subsurface geological information. In reality, there are other subtle differences that distinguish seismic sections from a geological cross-section and much computer time is required to remove 'artefacts' which are inherent in the acquisition and processing of seismic data. However, there is insufficient space to detail these here.

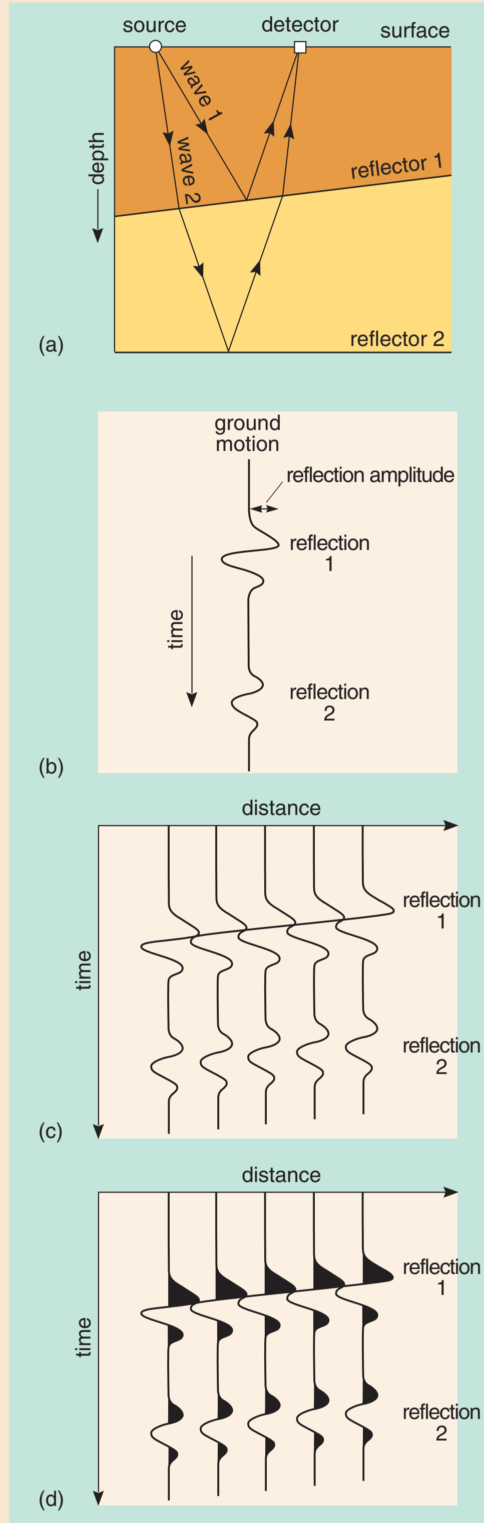

Figure 4.24 Seismic reflection surveying: (a) seismic reflection and refraction; (b) a seismic trace —reflection 1 has a higher amplitude than reflection 2; (c) a diagrammatic seismic section, composed of seismic traces from many shot points; (d) shading of the right-hand half of the wave to make the reflections more easily visible.