The Carbonate Seismic Scorecard

NCS = Noncarbonate structures, SWCS = Shallow-water carbonate structures; C = Common, P = Possible, R = Rare, ROP = Ruling-out parameter

Parameter category	Structure type / Parameter	Arc volcanoes	Other volcanoes (e.g. seamounts, hotspots, volcanic ridges, other non-arc volcanoes)	Salt diapirs and pillows – Shale and mud diapirs	Compressional features (pop-ups, folded layers, foldbelts and inverted structures)	Basement highs (horsts)	Erosional remnants	Carbonate platforms, shelves, buildups and ramps (SWCS)	Raw score NCS YES: -1 (each) SWCS YES: +1 NO: 0 Can't tell: 0	Data quality (or info source) factor x1: Very low x5: Very high	Weighted score (Raw score X data quality factor)
Morphology	Map view	**C:** Sub-circular, circular. elongated when two or more structures merge.	**C:** Sub-circular, circular if subaerial. Sub-circular to elongated, if subaqueous (spreading ridge type of volcanoes). elongated when two or more structures merge.	**C:** Circular to elongated. **P:** Other geometries when merging of structures.	**C:** elongated.	**C:** elongated.	**C:** Any, from sub-circular to elongated.	**C:** Sub-circular to elongated if isolated. **C:** Elongated if attached (shelf), mimicking the continental shelf .			
	Surface texture	**C:** Volcanic depression: Crater (< 1 km diameter) or caldera (up to 100 km diameter and 1 km depth), often associated with ridges and deeply incised valleys and/or dendritic drainage. **P:** Secondary smaller cones. **ROP:** Karst landform (see carbonate box for description).	**C:** Volcanic depression: Crater (< 1 km diameter) or caldera (up to 100 km diameter and 1 km depth), often associated with ridges and deeply incised valleys and/or dendritic drainage. **P:** Secondary smaller cones. **ROP:** Karst landform (see carbonate box for description).	**C:** Any. **ROP**: Fluvial patterns or incised valleys. Karst landform (see carbonate box for description).	**C:** Any. Often fault and/or fracture systems from sub-parallel to perpendicular to main tectonic vergence.	**C:** Subaerial erosional features (e.g. fluvial patterns, incised valleys) **C:** Intense fault/fracture systems.	**C:** Any. **P:** Subaerial erosional features (e.g. fluvial patterns, incised valleys).	**C:** Elongated shapes following (rimming) the shelf margin **P:** Sub-circular patch reefs partially covering the inner platform. **P:** Numerous karst landforms (circular collapse features, ranging in diameter and depth from a few meters to some hundred of meters, and remnant towers). **P:** No margin rim or patch reefs if building potential is poor (e.g. most heterozoan carbonates). **ROP:** Well-developed fluvial pattern			
	Vertical profile or thickness change	**C:** Cone, truncated cone (flat, concave or jagged top).	**C:** Cone, truncated cone (flat, concave or jagged top). **P:** Convex-upward shield shape in shield volcanoes.	**C:** Thickening in the salt or mud layer.	**C:** No thickness change in the pretectonic section, except in the case of an erosional unconformity at the top. Thickness change in the syntectonic section.	**C:** No thickness change in the pre-rift stratigraphic section but only in overlying and lateral syntectonic layers - Sedimentary basement: uniform thickness - Crystalline basement: Apparent thickness change (lack of base and faulted blocks).	**C:** Thickness change in the section only where differential erosion occurs, which is commonly the case.	**C:** Greater thickness than basinal coeval sediments (except in case of nearby siliciclastic sediment sources). **C:** Shape styles including mounds, half-walnut, bell shapes, terraces, mesas, aprons, cones, mushrooms. **P:** Platform margin thicker than platform interior.			
Regional scale parameters	Tectonic setting (check regional stratigraphic and tectonic columns)	**C:** Convergent plate boundary associated with the subduction of an oceanic plate. **C:** Known coeval arc volcanic activity in the area	**C:** Divergent plate boundary, back-arc opening basins, intracontinental extension settings, hot spots under oceanic and continental plates. **C:** Known coeval non-arc volcanic activity known in the area	**Salt: C:** Salt Precipitation: Early post-rift setting (Messinian salt in the Mediterranean being an exception). Mobilization: Triggered either by high sedimentation rate (passive margin) or compressional tectonics (compressional or transpressional plate boundaries). **Mud: C:** Mud deposition: Passive margin setting. Mobilization: Triggered either by high sedimentation rate (passive margin) or compressional tectonics (compressional or transpressional plate boundaries).	**C:** Compressional and transpressional plate boundaries, from foldbelt to inner foreland domains. **P:** Compressional belts related to gravitational sliding in outer offshore passive margin or large delta fronts.	**C:** Extensional settings. Transtensional (pull-apart) basins.	**C:** Any tectonic setting.	**C:** Any tectonic setting, except foredeep settings and areas with large coeval siliciclastic imputs (e.g. fluvial deltas). **C:** Known occurrence of time-equivalent carbonates. **R:** Foredeep settings and areas with large coeval siliciclastic imputs (e.g. fluvial deltas), associated with small-sized SWCD developing during transgressive phases.			
	Palaeogeographic setting	**C:** Grow on structural highs produced by subduction zone heat flow + compressional thickening + magmatism. Likely to be associated with crustal fractures and faults. **C:** Resulting in islands or submarine highs in front of an elongatedd marine depression (back-arc basin) or in elongatedd mountain ranges at continental margins.	**C:** Forming in any paleogeographic setting, resulting in submarine or subaerial positive structures.	**Salt: C:** Deep evaporite paleo-basins (up to more than 1000 m paleodepth) tectonically restricted. **Mud: C:** Deltaic system with high sedimentation rate and accretionary prisms.	**C:** Any. **C:** Forming submarine and continental ridges and chains.	**C:** Evolving from continental (fluvial or lacustrine during syn-rift and early sag phases) settings to shallow and deep marine settings (late sag to post-rift phases).	**C:** Originating from sub-aerial to shoreline erosion of previously deposited sediments. Representing paleo coastal cliffs or continental mountains and hills. **R:** Forming on top of isolated paleo-highs.	**C:** Low paleo-latitudes and shallow-water settings: Continental shelves, isolated paleo-highs, intra-continental areas (epeiric seas) or lacustrine (mainly in a sag tectonic phase) settings. **P:** Middle paleo-latitudes. Relatively shallow-water (down to ~80 m water depth) settings: Etherozoan carbonates with poor building potential.			
	Regional pattern	**C:** Arc shape. Arc width mostly ranging between 10 and 100 km. Arc length mostly ranging between 50 and 1000 km. Regular volcano spacing along the arc rangeing usually from 0 km to 50 km. Distance between volcanic front and back-arc basin up to 300 km.	**C:** Isolated hotspots, ridges of volcanoes along fracture zones or volcanic fields (usually 10 to 100 volcanic edifices grouped in clusters).	**C:** Extensive groups of single structures, which can often merge and form belts parallel to continental margins . **R:** Isolated features, when feeding or mobilization is poor.	**C:** Associated with other structures with similar strike.	**C:** Any.	**C:** Either isolated features or several structures with the same trend (same paleobathymetry or paleoshoreline), which formed as the final result of the same substrate affected by differential erosion.	**C:** Structures lining up along up-thrown side of faults, other paleo-geographic highs or on shelf and platform edges. **C:** Occurring isolated on top of an isolated high.			
	Gravity and Magnetics HR data: Max resolution 500 m LR (Satellite): Max resolution 5 km	**Grav: C:** High contrast, following the arc shape, between the positive anomaly of the arc and the associated sedimentary wedge. **Mag: C:** High amplitude anomaly.	**Grav: C:** Positive anomaly. **Mag: C:** High amplitude anomaly.	**Grav:** - **Mostly halite: C:** Negative anomaly. - **Shale: C:** Negative anomalies. **Mag: C:** No anomaly.	**Grav: Thin and thick skinned foldbelts: C:** Positive anomaly with foldbelt's shape. **Mag:** - **Thin skinned: C:** No anomaly. - **Thick skinned (involving basement): C:** Anomaly.	**Grav: C:** Positive anomaly. **Mag:** **Crystalline basement: C:** Anomaly. **Sedimentary basement: C:** No anomaly.	**Grav: C:** Positive anomaly. **Mag: C:** Depending on remnant composition.	**Grav: C:** Moderate positive anomaly (only detectable with HR data). **Mag: C:** No anomaly **P:** Anomaly only with carbonates occurring on top of a basement high.			

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Seismic response	Top reflection	**Subaqueous: C:** Bright continuous positive reflector. **Subaerial: C:** Discontinuous and/or dimming reflector. **P:** jagged geometry	**Subaqueous: C:** Bright continuous positive reflector. **Subaerial: C:** Discontinuous and/or dimming reflector. **P:** High-amplitude positive reflector. Jagged geometry. **Extrusives: C:** Bright continuous positive reflector.	**C:** Extremely variable, either high amplitude continuous or dimming and changing sign, even in the same area, depending on evaporite lithology (low acoustic impedance if pure halite, very low if mud, high with anhydrite contribution) and overburden composition (lower acoustic impedance in clastics, higher in carbonates). **P:** Caprocks showing a bright positive reflector.	**C:** Continuous positive reflector. **R:** Discontinuous and/or dimming reflector when folded section is severly fractured or very low acoustic impedance.	**C:** Continuous positive top reflector **P:** Indistinct or discontinuous reflector when structure has a very low acoustic impedance or weathered top (e.g. some crystalline basements).	**C:** Continuous positive top reflector **R:** Indistinct or discontinuous reflector when structure has a very low acoustic impedance or weathered top.	**C:** High-amplitude positive continuous reflector. **P:** Positive semi-continuous reflector. **P:** Karst topography. **R:** Negative or indistinct reflector (e.g. gas effect in very high porosity carbonates).			
	Internal seismic pattern	**Internal core: C:** Mainly chaotic or reflector-free. **C:** Bursting amplitudes (high amplitude positive discontinuous) reflections. **External core: C:** Semi-continuous reflectors, possibly alternating with chaotic reflection zones, running parallel to side reflectors and forming a cone-in-cone architecture. **P:** Amalgamated cone-in-cone in larger structures, suggesting amalgamated volcanoes.	**Internal core: C:** Mainly chaotic or reflector-free. **C:** Bursting amplitudes (high amplitude positive discontinuous) reflections. **External core: C:** Semi-continuous reflectors, possibly alternating with chaotic reflection zones, running parallel to side reflectors and forming a cone-in-cone architecture. **P:** Amalgamated cone-in-cone in larger structures, suggesting amalgamated volcanoes.	**C:** Chaotic to transparent. **P:** Isolated portions with high-amplitude strongly folded semi-continuous reflectors if rigid lithologies occur within the mobile matrix (anhydrite, carbonate strings, fragments of surrounding layers). **ROP:** Undisturbed parallel reflectors.	**C:** Continuous bent reflectors usually parallel to top reflector (unless this is an erosional unconformity). **P:** Reflector continuity decreased down to chaotic by occurrence of internal faulted and fractured zones **R**: Lateral seismic facies change clearly visible within the structure.	**Crystalline basement: C**: Chaotic or discontinuous seismic pattern. Seismic frequency significantly lower than encasing deposits. **Sedimentary basement: C:** Parallel continuous reflectors, often showing truncation and angular unconformities. **R**: Lateral seismic facies change clearly visible within the structure.	**C:** Continuous to semicontinuous reflectors (more or less parallel, depending on nature of the remnant), showing truncation against top and side boundaries. **R**: Lateral seismic facies change clearly visible within the structure.	**C:** Several possible different seismic reflector patterns: mounded, progradational, chaotic, transparent, parallel (in the platform), inclined (in the slope). **C:** Internal sequences. **C:** Seismic frequency lower than encasing deposits. **P:** Internal karst-related collapse. Truncated reflectors at the top. **ROP:** Bursting isolated patchy amplitudes, heavily folded reflectors, cone-in-cone architecture.			
	Base reflection	**C**: Disrupted base reflection or none due to an intruding feeding chimney. **R:** Continuous base reflection only when a 2D seismic section does not include the feeding chimney.	**C**: Disrupted base reflection or none due to an intruding feeding chimney. **R:** Continuous base reflection only when a 2D seismic section does not include the feeding chimney or in effusive products far from the point of emission.	**C:** High amplitude continuous reflector in thinning-upward bodies, most likely to be positive when pure halite or mud are involved, changing to negative with a high anhydrite component or low acoustice impedance underburden (e.g. weathered basement). **P:** Losing continuity or disappearing, often showing a seismic pull-up-like geometry, in thickening-upward or sub-vertical sided structures, or in strongly allochtonous layers (canopies). Subject to migration artifacts.	**P:** Missing (because of pop-up geometry or seismic response dramatically deteriorating). **P:** Continuous reflection almost parallel to internal reflectors (low-angle detachement) or cutting through reflectors, showing offset (high-angle faults).	**C:** None, neither a visible surface nor a uniform seismic facies change.	**C:** Clear and continuous base reflection.	**C:** Clear and continuous, positive or negative **P:** Showing disruption-discontinuity only below a structure thicker than 1000-1500 m. **R:** Indistinct, however associated with an abrupt and uniform seismic facies change, in case of similar acoustic impedance between carbonates and substrate. **ROP**: Disruption in structures for structures thinner than 1000-1500 m.			
	Side reflection character	**C:** Either a continuous or discontinuous reflector. **P:** Amplitudes in structures with subaerial craters (flattish tops) getting stronger from upper to lower side. **R:** Lateral truncation.	**C:** Either a continuous or discontinuous reflector. **P:** Amplitudes in structures with subaerial craters (flattish tops) getting stronger from upper to lower side. **R:** Lateral truncation.	**C:** Continuous and high amplitude at flat or low angle interfaces (top and far sides, where feeding layer is), likely to get fuzzy and discontinuous, or even disappear, at steep flanks or if and where the structure thickens upward.	**Unfaulted folds: C:** Continuous high amplitude positive reflector from top to sides. **Faulted structures (pop-ups, thrustbelts etc) C:** Chaotic seismic patterns along faults. **P:** Stratal offset.	**Crystalline basement: C:** Either continuous or no clear side reflection surface (especially on steep flanks, with a gradual gradation from chaotic low-frequency to more continuous, higher-frequency seismic facies of later deposits). **Sedimentary basement: C:** Truncation associated with fault-related lateral surfaces.	**C:** Continuous, irregular surface separating the structure from younger sediments. Need to see truncation and abrupt lateral change of seismic facies.	**C:** Continuous positive reflection along sides. **P:** Nearly indistinct reflection, changing into a clear onlap surface, or just a lateral seismic facies and/or frequency change.			
	Encasement (overlying and surrounding reflector character)	**C:** Undisturbed onlap (max 10-15°) on top and sides. **P:** Differential compaction features in younger deposits (gentle folding dying out within 0.5 TWT sec above the structure with possible small collapse features).	**C:** Undisturbed onlap (max 10-15°) on top and sides. **P:** Differential compaction features in younger deposits (gentle folding dying out within 0.5 TWT sec above the structure with possible small collapse features).	**C:** Surrounding reflectors appearing as being pushed upwards. (not to be confused with differential compaction, tectonic folding being more extended vertically, affecting reflectors up to some TWT seconds above the structure, unless they are cut by an erosional unconformity). **C:** Generally no onlap, or a disturbed onlap (> 10-15°). **P:** Extensive collapse features in the overburden.	**C:** Surrounding and overlying reflectors appearing as being pushed upwards. This folding can affect reflectors up to some TWT seconds above the structure, unless they are cut by an erosional unconformity. - Posttectonic layers: Undisturbed reflectors (geometry depending on setting). - Syntectonic layers: Disturbed (> 10-15°) onlap and condensed section of overlying reflectors with lateral reflectors pinching out on the structure (growth strata).	**C:** Onlap (either steep and disturbed or not) on top and sides. Usually associated with synsedimentary growth strata in the adjacent lows and condensed section on top. **P:** Differential compaction features in younger deposits (gentle folding dying out within 0.5 TWT sec above the structure with possible small collapse features).	**C:** Undisturbed onlap (max 10-15° on top and sides. **P:** Differential compaction features in younger deposits (gentle folding dying out within 0.5 TWT sec above the structure with possible small collapse features).	**C:** Tectonically undisturbed (max 10-15° dip) onlap on top and sides. Differential compaction features in younger deposits (gentle folding dying out within 0.5 TWT sec above the structure with possible small collapse features). **P:** Downlap on top if a prograding delta comes after carbonate deposition. **R:**Tectonically disturbed onlap (> 10-15° dip) if the SWCD formed during or just before an active tectonic phase.			
Growth patterns	Source-Structure geometric or genetic relationship (including feeding or growing relationship with other similar structures)	**C:** Intruding chimney below the structure: an elongatedd vertical volume of chaotic or transparent reflectors. **P:** Reflectors around the chimney being bent upwards by the chimney itself. **P:** Bursting positive disrupted or discontinuous reflectors near or far below the structures represent feeding sills.	**C:** Intruding chimney below the structure: an elongatedd vertical volume of chaotic or transparent reflectors. **P:** Reflectors around the chimney being bent upwards by the chimney itself. **P:** Bursting positive disrupted or discontinuous reflectors near or far below the structures represent feeding sills.	**C:** Connected to one or more feeding layers (autochthonous and/or allochthonous), which are commonly characterized by extremely variable thickness (possibly down to 0 thickness), transparent or chaotic seismic facies and which can connect to other similar structures.	**C:** Associated with similar structures, which can include different stratigraphic units, having the same vergence.	**C:** Associated with other structural highs, at a regional scale, which are usually overlain by an overburden of coarsely the same age.	**C:** Isolated structures or more structures related to the synchronous erosion of the same rock unit (e.g. paleoshoreline). **ROP:** Related structures at significantly different paleobathymetry or paleoaltitude.	**C:** Isolated structures or amalgamation of nearby structures. **C:** Basinal sediments reflectors (top and internal) with lower amplitude and higher frequency and continuity than buildups and platforms. **R:** Isolated bursting and fragmented reflectors below the structure, only occurring if SWCD grew on top of a volcanic basement (but in this case a clear carbonate base or abrupt facies change should be seen). **ROP:** Feeding layers or intruding chimney			
	Progradation	**C:** No progradation.	**C:** No progradation in most isolated volcanic edifices which are not connected to a ridge system. **P:** Well-developed prograding "Lava deltas", building up in a transitional setting (close to shoreline), only when an extremely high amount of basaltic lava is produced (mainly in a volcanic ridge system such as a divergent plate system or intra-continental extension). Clinoforms with a similar geometry to sedimentary deltas, but usually showing a bright hard parallel-reflector top, trasparent to well defined foresets, quite bright lower slope to basinal reflectors (not dimming basinward) and steep slopes (30°-35°).	**C:** None within or bounding the structure.	**C:** None within the structure. **R**: Progradation features within folded-thrusted shallow-water strata.	**C:** None within the structure. **R:** Progradation features surrounding the structure.	**C:** None within the structure. **R:** Within the structure if internal strata are made of shallow-water deposits . **R:** Progradation features surrounding the structure.	**C:** Either not visible or visible within or around the structure, showing high-amplitude internal topsets and clinoform break with downlap terminations dimming basinward.			
	Debris, Talus and Flow character	**C:** Fans and mounds common on the flanks. Slumps, avalanches, and debris flows associated with discontinuous, chaotic seismic facies. - Lava flow seismic amplitude not decreasing (or even increasing) moving away from the structure. - Relative timing: Most of the debris, talus and eruptive products coming from the structure most likely to be deposited prior to any trasgressive layers, which then will onlap the entire structure and its debris. **R:** Important magmatic reactivation of the same volcanic edifice after a long time period (some M.Y.) causing interfingering of debris and/or lava with younger sedimentary layers.	**C:** Fans and mounds common on the flanks. Slumps, avalanches, and debris flows associated with discontinuous, chaotic seismic facies. - Lava flow seismic amplitude not decreasing (or even increasing) moving away from the structure. - Relative timing: Most of the debris, talus and eruptive products coming from the structure most likely to be deposited prior to any trasgressive layers, which then will onlap the entire structure and its debris. **R:** Important magmatic reactivation of the same volcanic edifice after a long time period (some M.Y.) causing interfingering of debris and/or lava with younger sedimentary layers.	**C:** No seismic-scale detrital body related to the structure. **P:** Cusp and hook geometries.	**C:** Not visible at a seismic scale **P:** Deformed syntectonic sand-prone fans (high-amplitude), debris flows, talus and slumps around the structure.	**C:** Sand-prone bodies (high-amplitude) and debris-breccia accumulation (chaotic seismic facies) at the lower sides of the structures (syntectonic section).	**C:** No seismic scale debris. **R:** Some seismic-scale debris at the lower sides of the structure.	**C:** High-amplitude reflectors (wings) dimming away from the structure, associated with fringing debris aprons interfingering (time equivalent) with pelagic surrounding layers: **P:** Collapse products, associated with scalloped or steep sided margins, showing either the same seismic character as the platform (if intact) or a chaotic seismic pattern (if a debris flow) **ROP:** Interpreted debris not dimming away from the structure.			