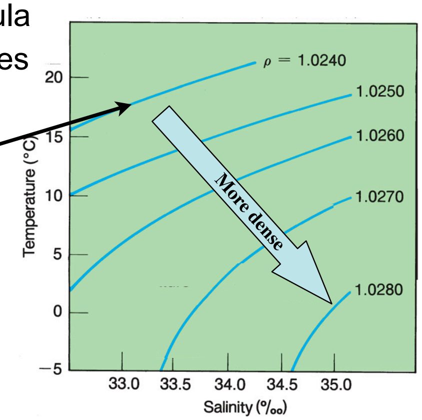
Density of Sea Water ρ

- Definition: mass of substance per unit volume
  - Grams per cm^3 (=cc, =ml)
- ρ of pure water at 4˚C = 1.0 g/cm^3
- Salts make water more dense
  - Salinity = grams salts per kilogram water
    - = parts per thousand or ‰
    - 1 g/kg = 0.1 %
  - In 35 g/kg seawater (at 4˚C) density = 1.028
- Temperature also affects density
  - Warm water expands, density decreases
  - Cold water contracts, density increases

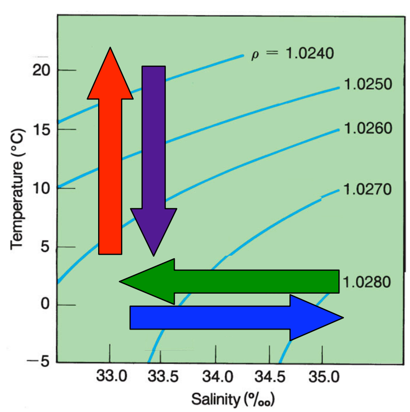
T-S Diagrams

- Density is calculated from T & S
  - Uses a complex formula
  - Results printed in tables
  - Easier to use is a T-S diagram
  - Isopycnals = lines of constant density
  - Density increases from upper left to lower right



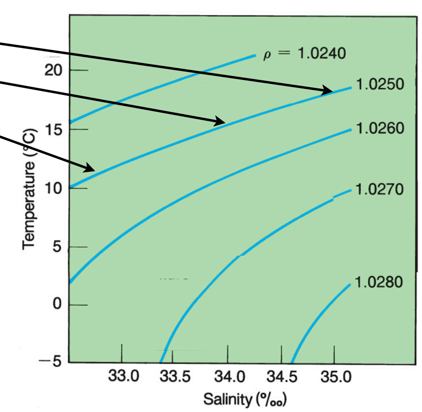
T-S Diagrams

- T&S have opposite effects on ρ
  - ↑T = ↓ρ
  - **but ↑S = ↑ρ**
  - ↓S = ↓ρ
  - **but ↓T = ↑ρ**



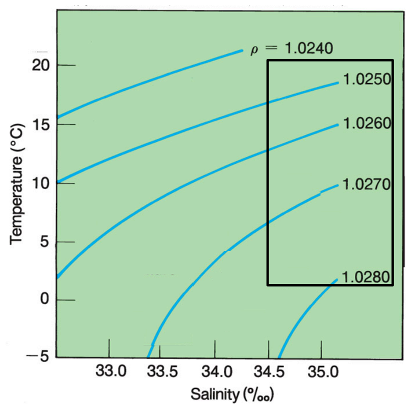
T-S Diagrams

- Many combinations of T&S give the same ρ
  - ρ=1.025
    T=18, S=35
    T=15, S=33.9
    T=10, S=32.5
  - Changes in T&S counteract



T-S Diagrams

- Small changes in ρ very important
  - Most salinities
    34.5 < S < 35.5
  - Most temps
    3° < T < 20°C
  - Most densities
    1.025 < ρ <1.028

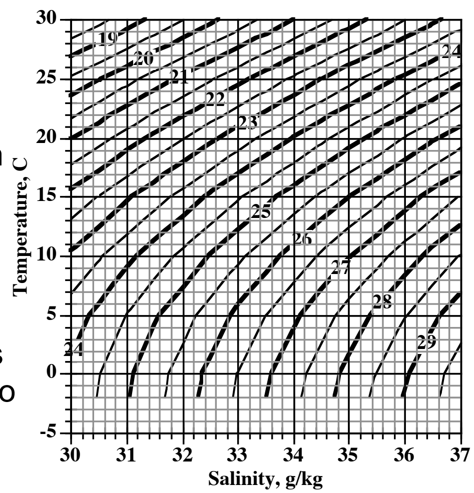


Density of Sea Water

- Sigma-t (σ_t) is an abbreviation or shorthand for density.
  - (ρ-1) * 1000.
  - ρ=1.025, σ_t=25.0; ρ=1.028, σ_t=28.0
- Used because small differences in density have important effects on water movement.

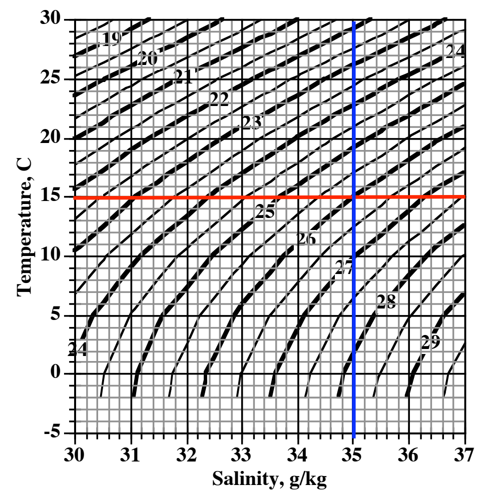
Determining Density

- T-S diagram a graphical display of σ_t values
  - Read directly from T & S
  - Simpler than solving the formulas
  - Today instruments are programmed to make calculations automatically



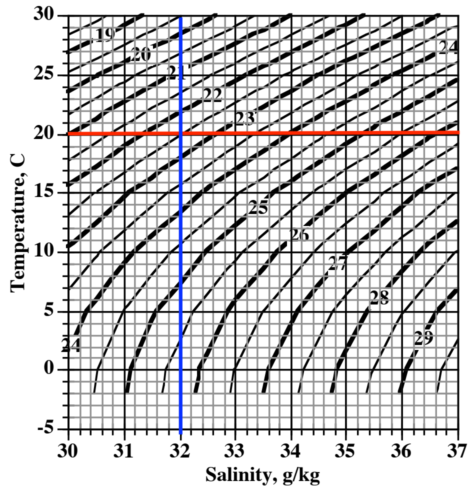
Determining Density

- Example #1
  - T = 15° C
  - S = 35 g/kg
  - σ_t = ?
    - 26
  - ρ = ?
    - 1.026 g/cm³



Determining Density

- Example #2
  - T = 20° C
  - S = 32 g/kg
  - σ_t = ?
    - 22.5
  - ρ = ?
    - 1.0225 g/cm^3



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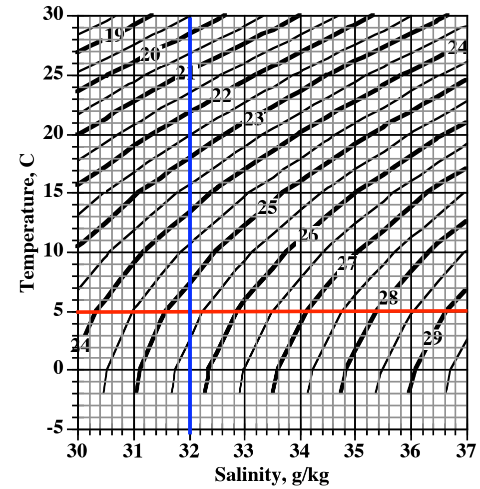
Determining Density

- Example #3
  - T = 5° C
  - S = 32 g/kg
  - σ_t = ?
    - 25.3
  - ρ = ?
    - 1.0253 g/cm^3



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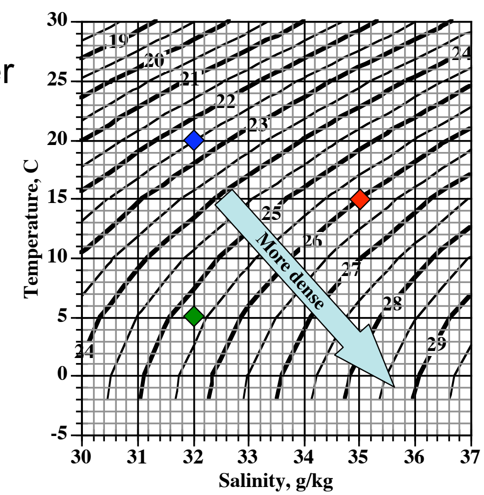
Determining Density

- Rank the examples in order of increasing density
  - #2 σ_t = 22.5
    - ρ = 1.0225 g/cm^3
  - #3 σ_t = 25.3
    - ρ = 1.0253 g/cm^3
  - #1 σ_t = 26.0
    - ρ = 1.026 g/cm^3



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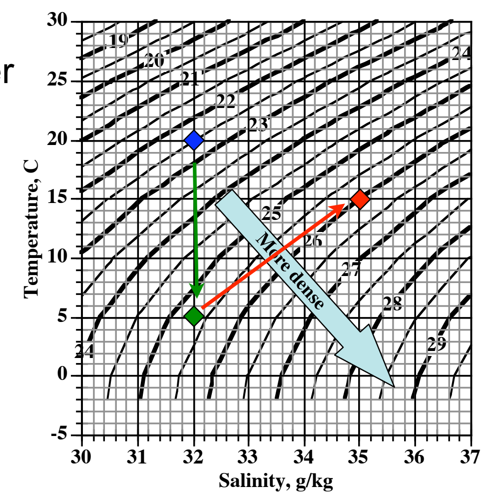
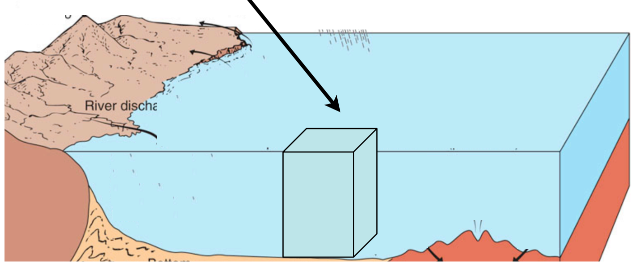
Determining Density

- Rank the examples in order of increasing density
  - #2 σ_t = 22.5
  - ↓T @ same S = ↑ρ
  - #3 σ_t = 25.3
  - ↑S overcomes ↑T = ↑ρ
  - #1 σ_t = 26.0



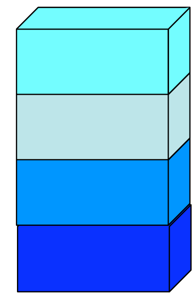
Vertical Stratification

- Water column
  - Hypothetical vertical section of water from surface to bottom
    - Square cross-section



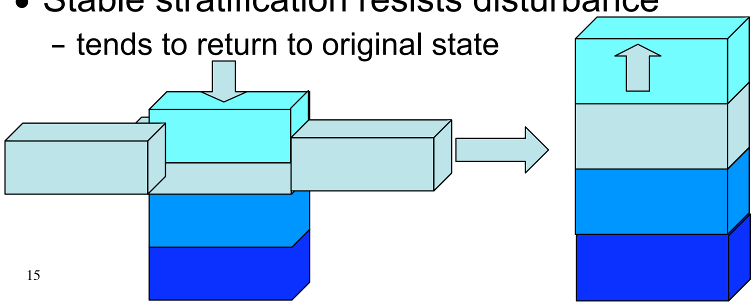
Vertical Stratification

- Stratification is the vertical density layering of water column
  - Waters of different density at different depths
  - Buoyancy — less dense water tends to float atop more dense
- Density stratification
  - Warmer water floats & cooler water sinks (constant salinity)
  - Fresher water floats & saltier water sinks (constant temperature)



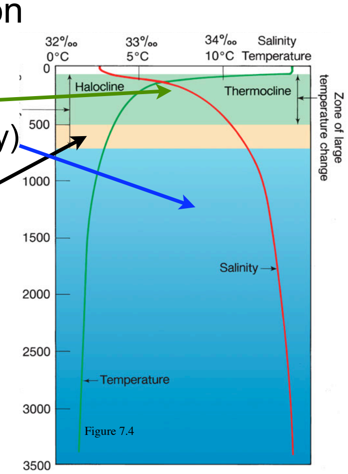
Vertical Stability

- Stability of stratified water column
  - Depends on relative density of layers
  - Less dense water atop more dense water = stable
    - It will persist until disturbed
- Stable stratification resists disturbance
  - tends to return to original state



Examples: Stability

- Thermal—Lake Washington
  - Surface warms in summer
  - Warm (lower-density) water lies atop cool (higher-density) water
  - Thermocline: boundary between layers of different temperature
    - Rapid change in temperature with depth



Examples: Stability

- Haline—Puget Sound
  - River runoff meets sea water at the river mouths
  - Fresh or brackish (low-salinity) water lies atop higher-salinity water
  - Halocline: boundary between layers of different salinity
    - Rapid change in salinity with depth

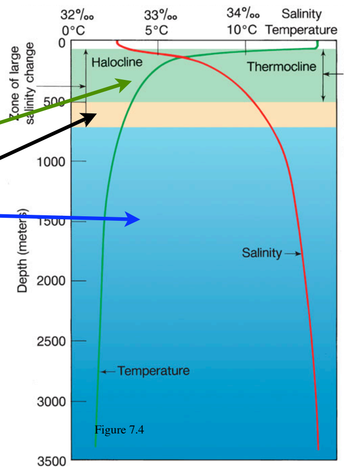


Figure 7.4

Examples: Stability

- Pycnocline
  - Boundary between 2 layers of different density
  - If there is a thermocline or halocline, there is also a pycnocline.
- Mixed layer
  - Layer above the pycnocline
  - Homogenized by wind mixing
  - Nearly uniform properties over depth.

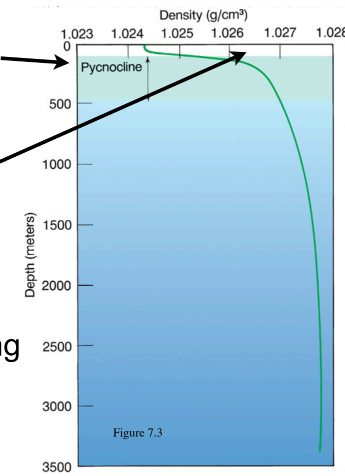


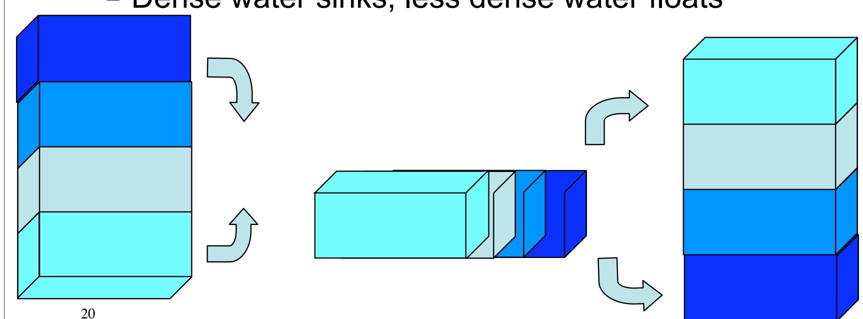
Figure 7.3

Vertical Stability

- In general, the oceans are stable
  - Greater density difference between layers = stronger stability
- If not, they would move until stable
  - Vertical instability occurs in certain situations in the oceans
- Neutral stability = unstratified
  - Density is same at all levels
- In general, T has greater effects than S
  - Some important exceptions
  - Puget Sound, Mediterreanean

Instability

- Instability of stratified water column
  - More dense water atop less dense
  - Initiates rather than resists motion
  - Dense water sinks, less dense water floats



Examples: Instability

- Thermal—Polar seas in winter
  - Strong cooling
  - Dense water at the surface
  - Sinks below warmer water beneath
  - Major factor in global density-driven ocean currents
- Haline—Polar seas in winter
  - Sea ice freezing & "brine exclusion"
  - Sea ice is almost pure fresh water
  - Salt remains in sea water, raising salinity & density
  - Sinks below less-saline water beneath.

Examples: Instability

- Haline—Mediterranean
  - Evaporation in desert climate
  - Creates high-salinity surface layer
  - Denser than the lower-salinity water beneath, and so it sinks.

Stratifying processes

- What external natural processes enhance stratification?
  - Anything that changes density
    - Heating & cooling
    - Freshwater runoff
    - Evaporation & precipitation
    - Freezing & melting of sea ice

Stabilizing processes

- What external natural processes enhance vertical stability?
  - Surface solar heating (T)
  - Freshwater runoff (S)
  - Rain (S)
  - Melting of sea ice (S)

Destabilizing processes

- What external natural processes enhance vertical instability?
  - Surface cooling (T)
  - Sea ice formation (T & S)
  - Surface evaporation (S)
  - Sea-floor heating (T)

Destratifying forces

- What external natural processes break down vertical stratification?
  - Forces that move water rather than exchanging heat or fresh water
  - Wind mixing
  - Fast, turbulent currents (esp. over or around bathymetric barriers)
  - Instability-induced convection

The Real Ocean

- Vertical changes in both T & S
  - If both T & S increase, what happens to density & stability?
  - If both T & S decrease, what happens to density & stability?
- Must determine density from T & S to answer this question

The Real Ocean

- Curious example—the Red Sea
  - Surface = 30˚C, 42.5 g/kg
    - Heating & evaporation
  - Bottom = 36˚C & 257 g/kg
    - Rift valley & hydrothermal vents
- Vertically stable or unstable?
  - Stable - S overcomes T
- Puget Sound in winter
  - Surface = 4˚C, 20 g/kg
  - Deep = 8˚C, 31 g/kg
  - Stable because low surface S overcomes low T