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Assessing Leak Paths in the Cement Sheath of a Cased Borehole by Analysis of Monopole Wavefield Modes

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Abstract. Evaluation of possible leakage pathways of CO_2 injected into geological formations for storage is essential for successful Carbon Capture and Storage (CCS). A channel in the borehole cement, which secures the borehole casing to the formation, may allow CO_2 to escape. Risk assessment and remediation decisions about the presence of such channels depend on channel parameters: radial position r from the center of the borehole; channel thickness d; azimuthal position φ of the channel; and azimuthal extent θ of the channel. Current state-of-the-art cement-bond logging technology, which uses only the first arrival at a centralized borehole receiver, can diagnose limited details about CO_2 leak channels. To accurately characterize the possible leak paths in the cement, we use a 3-dimensional finite-difference method to investigate the use of the abundant data collected by a modernized monopole sonic tool that contains an array of azimuthally distributed receivers. We also investigate how to improve the tool design to acquire even more useful information. For cases where borehole fluid is either water or supercritical CO_2, we investigate various receiver geometries, multimodal analyses of multi-frequency data to discover the type of logging tool that provides the best information for CCS management. We find that an appropriate choice of wave modes, source frequencies, source polarities, and receiver locations and offsets provides sensitivity to d, φ, θ. The amplitude of the first arrival from a monopole source is sensitive to θ. Amplitudes at receivers at different azimuths are sensitive to φ. The slow Stoneley mode (ST2) velocity is sensitive to d, but ST2 is not easy to pick when θ and d are small. Further improvement is necessary to provide comprehensive information about possible flow channels in casing cement.

AMS subject classifications: 86A15

Key words: Greenhouse effect, CO_2 leak channel, cement bond evaluation, borehole acoustic logging, casing wave, Stoneley waves.

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1 Introduction

Carbon capture and storage (CCS) is essential to mitigating the "greenhouse" effect and ocean acidification. Geological storage involves injecting large amounts of CO_2 into underground formations, followed by measurement, monitoring, and verification of the surrounding site to ensure that no CO_2 leaks out [1, 2]. Evaluation of possible leakage pathways is essential [3], as it also is for plug-and-abandon activities in petroleum wells [4–7].

Fig. 1 shows some of the many possible leakage pathways that may occur in or near to a wellbore [8], many of which may not be detected using conventional well-log analysis. The leak paths labeled b and c in the cement plug cannot be evaluated by well logs. Other leak paths may be detected by well logs [9, 10]. Boreholes are cased with steel that is cemented into place, so micro-debonding at the casing steel interface and fractures in cement are significant issues. In addition, possible leaks at the cement-casing (leak path a in Fig. 1) and cement-formation (leak path f in Fig. 1) interfaces (called I and II here) need to be distinguished. Detection of leaks in boreholes with multiple casing strings (one inside another) present even more challenges [4–7].

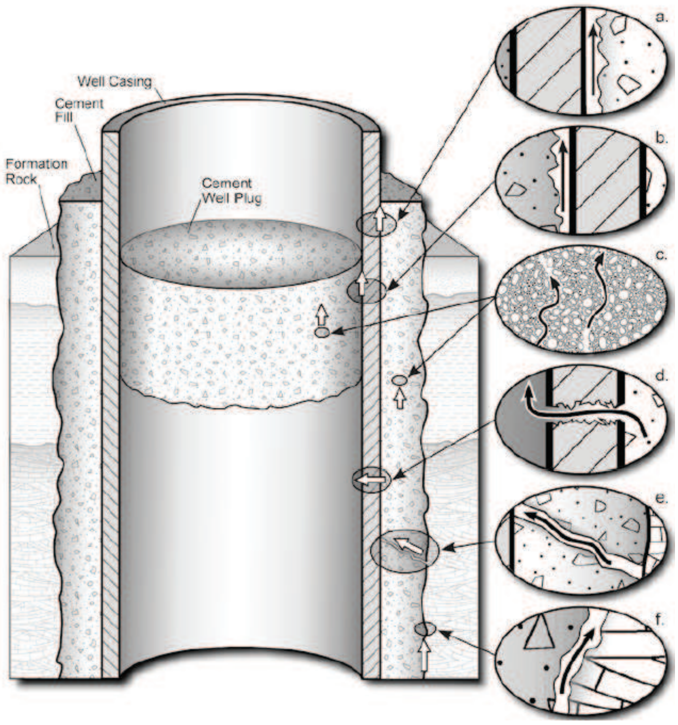

Figure 1: Possible leakage pathways: a) between casing and cement; b) between cement plug and casing; c) through pore space in cement resulting from cement degradation; d) through casing corrosion; e) through cement fractures; f) between cement and rock. From Figure 1 in [8].